Life Cycle Assessment of management options for beverage packaging waste

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Konceptuel ramme
Projektet omfatter en livscyklusvurdering af miljøpåvirkningen forbundet med bortskaffelsesmulighederne for emballageaffald fra drikkevarer i Danmark i 2018. Undersøgelsen blev udført af DTU Miljø i perioden november 2017 - juni 2018.

Danmark har et pantsystem, hvorunder visse drikkevarer (f.eks. øl, kulsyreholdige læskedrikke og vand) kun må markedsføres i genbrugelige eller genanvendelige emballager, der er dækket af et pant / retursystem.. Dette retursystem for emballageaffald udgør et optimeret genanvendelsessystem, der medfører høj indsamlingseffektivitet (f.eks. ved tilbagelevering af pant) og genanvendelse af højere kvalitet (f.eks. ved selektivt at fokusere på emballagematerialer af fødevarekvalitet). En forbedring af den nuværende genanvendelse af drikkevareemballage, kan ske ved at kigge på produkter, der endnu ikke er dækket af pant / retursystemet. Retursystemet er baseret på produkttyper (f.eks. kulsyreholdige drikke og vand) i stedet for på materialetype. Drikkevareemballageprodukter, der endnu ikke er medtaget i retursystemet, såsom juice, mælk og andre ikke-kulsyreholdige læskedrikke, kan være sammensat af de samme materialer som dem, der allerede er medtaget i det nuværende retursystem.

Formålet med projektet er at vurdere miljøpåvirkningerne af alternative bortskaffelsesmuligheder til håndtering af emballageaffald fra drikkevarer. Projektet ønsker at sammenligne miljøpåvirkningerne for de følgende muligheder:
- Højkvalitetsgenanvendelse via pant / retursystemet;
- Indsamling, sortering og genanvendelse via det eksisterende system for genanvendelige materialer;
- Forbrænding med restaffaldet.

Projektet undersøgte kun genanvendelige emballager. Sammenligningen blev udført for følgende drikkevareemballager:
- Plast: polyethylene terephthalate (PET) og højdensitets polyethylene (HDPE);
- Glas: klart, grønt og brunt;
- Metal: aluminium;
- Komposit: kartonbeholdere (75 %) med aluminium (5 %) og plastfolie (20 %) (fx Tetra Pak).

Målet med vurderingen er at:
- Vurdere miljøpåvirkningerne forbundet med tre bortskaffelsesmuligheder for emballageaffald fra drikkevarer for forskellige materialetyper og for en række miljøindikatorer
- Identificere den mindst miljøbelastende bortskaffelsesmulighed blandt de analyserede muligheder, for hver type drikkevareemballage og for de forskellige miljøindikatorer

Metode

Miljøvurderingen af bortskaffelsesmulighederne for drikkevareemballage blev udført ved en livscyklusvurdering (LCA). LCA er en standardiseret metode der bruges til at kvantificere potentielle miljøpåvirkninger forbundet med produktion, anvendelse og bortskaffelse af et produkt (ISO, 2006). LCA af systemer for affaldshåndtering tager højde for de potentielle miljøpåvirkninger, der er forbundet med bortskaffelse af produktet, såsom miljøpåvirkninger forbundet med materiale og energiforbruget til at behandle affaldet, samt potentielle emissioner fra selve affaldshåndteringen. Når materiale- og energiressourcer genanvendes, vil det erstatte anden materiale- og energiproduktion, hvorfor affaldshåndteringssystemet krediteres med de undgåede potentielle emissioner forbundet med denne erstatning.

Drikkevareemballageaffald kan forekomme i forskellige materialer (plast, glas, aluminium, karton og komposit). LCA'en blev udført for hvert materiale enkeltvis (betegnet monomateriale) for de tre bortskaffelsesmuligheder, vist i figur I.

Den funktionelle enhed valgt til denne undersøgelse var:
"Håndtering af emballageaffald fra drikkevarer (monomateriale) produceret i Danmark i 2017 og ikke i øjeblikket medtaget i pant / retursystemet. Affaldshåndteringen sker dels i Danmark og dels i andre europæiske lande. "

Reference flowet valgt til denne undersøgelse var:
"1 ton drikkevareemballage affald (mono materiale)".

Modelleringen af genanvendelse tog hensyn til mængden af urenheder i drikkevare emballageaffaldet i reference flowet (procent urenheder i emballageaffaldet), sorteringseffektiviteten, den teknologisk effektivitet i genanvendelsesprocessen (betegnet faktor A) og markedets respons for det genanvendte materiale (betegnet faktor B). Faktor A og B blev defineret som:

- A: Teknologisk effektivitet

Materialetab ved oparbejdning

$$A\ (\%) = \frac{\text{Materiale oparbejdet (kg)}}{\text{Totalt materiale sendt til genanvendelse (kg)}} \qquad (1)$$

- B: Markedsrespons

Mængden af erstattet primært (jomfruligt) materiale på markedet per mængde genanvendt (sekundært) materiale der sælges på markedet.

$$B\ (\%) = \frac{\text{Materiale undgået på markedet (kg)}}{\text{Total oparbejdet materiale (kg)}} \qquad (2)$$

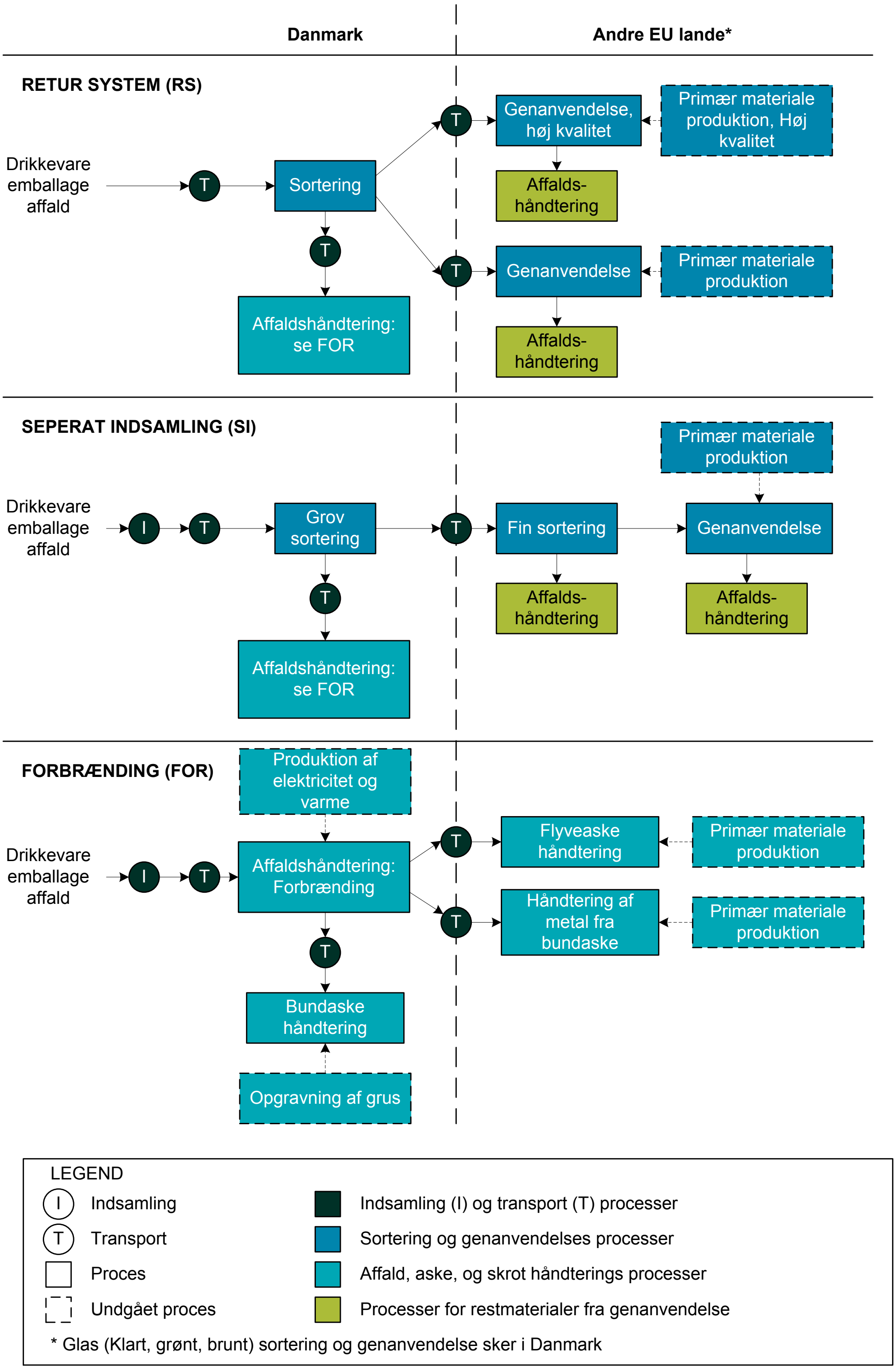
Den samlede genanvendelseseffektivitet i genanvendelsesprocessen blev således beregnet som:

Genanvendelseseffektivitet (%) = A · B (3)

Den samlede mængde genanvendt materiale fra det oprindeligt indsamlede drikkevare emballageaffald blev beregnet ud fra. (3) under hensyntagen til materialets renhed (for eksempel tilstedeværelse af urenheder), sorteringseffektiviteten og markedsresponsen som følger:

Totalt erstattet materiale (kg) = Reference flow (kg) · Renhed (%) · Sortering (%) · Genanvendelseseffektivitet (%) (4)

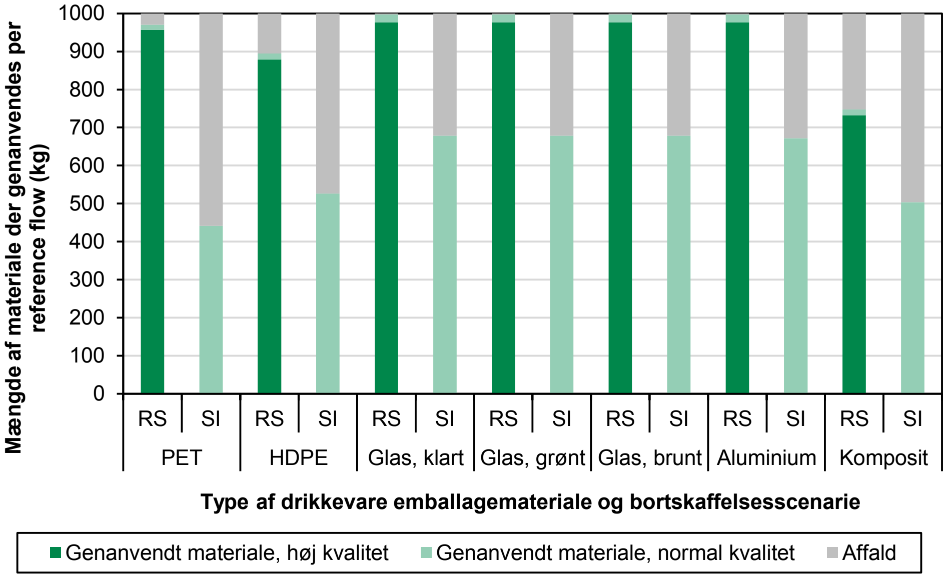
For at illustrere hvad effekten af en ændring af håndteringen af de forskellige mono materialer ville være, blev der udført en illustrativ scenarieanalyse hvor der blev foretaget en sammenligning af den nuværende håndtering af disse materialer med bortskaffelse via retursystemet for alle materialer. Komposit materialer er ikke omfattet af retursystemet, men da produkterne kan komme i denne emballage, blev der også modelleret et hypotetisk scenarie hvor 50 % af emballagen der skulle håndteres via retursystemet i stedet bliver produceret i kompositemballage der ikke kan håndteres i det nuværende retursystem og derfor forbrændes. Alle scenarier to udgangspunkt i resultaterne for mono materialerne, og ser derfor ikke på produktion af materialerne, og kan derfor ikke benyttes til at vælge hvilket materiale er det bedste emballage materiale.



Figur I. Generel struktur for de tre bortskaffelsesscenarier. Processerne for affaldshåndtering sker dels i Danmark, dels i udlandet, med undtagelse af glas der udelukkende behandles i Danmark.

Resultater og anbefalinger

Pant- og retursystemet medfører højere indsamlingseffektivitet samt øget materialegenanvendelse end det separate (kommunale) indsamlings- og genanvendelsessystem. Desuden giver materialer af fødevarekvalitet, der genanvendes via retursystemet, mulighed for genanvendelse af en tilsvarende høj kvalitet. Figur II illustrerer mængderne af genanvendt materiale af høj kvalitet og normal kvalitet, såvel som mængder af genereret affald for hver type drikkevareemballage, for retursystemet og det separate indsamlingssystem. Den højeste genanvendelse via retursystemet blev opnået for PET, glas og aluminium. Genanvendelseseffektiviteten for retursystemet var altid højere end genanvendelseseffektiviteten for den separate indsamling for det samme materiale.



Figur II. Materialer genanvendt med høj kvalitet og normal kvalitet samt mængder af genereret affald, for hver type drikkevareemballage, for retursystemet (RS) og det separate indsamlingssystem (SI). Resultater er vist per monomateriale reference flow.

Hvilken bortskaffelsesmulighed har den laveste miljøpåvirkning for hver enkelt drikkevareemballage (mono-materiale)?

I forhold til klima påvirkning fremkom retursystemet med den laveste miljøpåvirkning for all materialer. For PET og aluminium, fremkom retursystemet med de laveste værdier for henholdsvis 11 og 10 af de vurderede miljøindikatorer. For HDPE og komposit drikkevareemballage, gav forbrænding som bortskaffelsesmetode den laveste miljøpåvirkning for en række miljøindikatorer. Dette skyldtes de forholdsvis lavere miljømæssige fordele forbundet med genanvendelse af disse materialer, på grund af lavere oparbejdningseffektivtet og lavere miljøbelastning fra primærproduktion af HDPE og kompositmateriale. Det er vigtigt at nævne, at for alle de miljøindiktatorer, hvor retursystemet var bedre end forbrænding, var den næstbedste bortskaffelsesmulighed separat indsamling,

Hvilke konsekvenser er der forbundet med produktionen af drikkevareemballage?

LCA-resultaterne for den bedste bortskaffelsesmulighed varierede i størrelse, fordi materialer med stor miljøpåvirkning fra produktionen er forbundet med store fordele ved genanvendelse. Af denne grund sammenlignede vi LCA-resultaterne med miljøpåvirkningen forbundet med produktionen af de forskellige drikkevareemballager. Aluminium viste sig at være det materiale med den højeste samlede miljøpåvirkning fra produktionen, hvorfor den giver de største besparelser per ton, når det genanvendes. PET har højere miljøpåvirkninger fra produktionen end HDPE, hvorfor det også fører til de højere besparelser, når det genanvendes. Glas er per ton, materialet med den laveste miljøpåvirkning. Disse værdier bør dog ikke bruges alene, men skal altid overvejes i forhold til mængderne af de forskellige materialer, der skal bortskaffes. Endelig kan de ikke bruges til at identificere direkte hvilket materiale der bør foretrækkes i produktionsfasen, da det kun omfatter produktionen af selve materialet og ikke andre funktionaliteter.

Hvad er betydningen af bortskaffelsen af drikkevare emballage via retursystemet i Danmark?

De illustrative scenarier indikerede, at scenariet hvor al drikkevareemballage bortskaffes via retursystemet (med den nuværende effektivitet vi har i dag), ville føre til forbedringer i 13 ud af 14 miljøindikatorer, sammenlignet med scenariet med bortskaffelse via separat indsamling som det sker i dag. Scenarierne viste også, at hvis komposit materialer bruges som drikkevareemballage for at undgå at produktet skal håndteres via retursystemet, så vil forbedringerne ved retursystemet være mindre, da en mindre mængde materiale ville blive genanvendt da komposit materialer ikke på nuværende tidspunkt er en del af retursystemet, og heller ikke indsamles for genanvendelse i danske kommuner.

.

Resumé af det kritiske review

Reviewere

En kritisk gennemgang i henhold til ISO 14040/14044 blev udført af Line Geest Jakobsen og Trine Lund Neidel fra COWI A/S i marts 2018

Review processen

Reviewet involverede følgende faser:

- COWI udførte det første review i marts 2018
- DTU svarede på de spørgsmål der blev stillet af COWI, og rettede rapporten i forhold de kommentarer der var enighed om i reviewet fra marts 2018
- COWI evaluerede de rettelser der var lavet, og sammenfattede den endelige review kommentar.

Det kritiske review er vedhæftet i fulde i Appendix E i form af en tabel med kommentarer og svar. Hovedpunkterne fremhævet i det kritiske review er angivet nedenfor.

LCA-rapporten er blevet gennemgået med hensyn til overholdelse af de internationale standarder ISO 14040 og 14044. Rapporten viste sig i overordnet at overholde standarderne. Forfatterne anfører, at rapporten ikke er i overensstemmelse med standarden, da et review med inddragelse af et ekspertpanel ikke blev gennemført i projektfaserne. Et følgegruppemøde blev afholdt for at få kommentarer og kritik til rapporten, men et egentligt ekspertpanel blev ikke nedsat.

Det kritiske review gjorde klart, at det skulle være tydeligt hvilke materialer der ses på, da der kun ses på genanvendelige emballager, og ikke genbrugelige. Herudover blev det bedt at det tydeligere blev beskrevet hvilke mængder og materialer er med i analysen. Herudover understregedes det, at det er vigtigt med forklaringer omkring kvalitet, hvor der blev tilføjet yderligere beskrivelse. Der blev også efterspurgt følsomhedsanalyser ud over de tilføjede. Forfatterne tilføjede dedikerede afsnit om datakvalitetsvurdering, kritiske antagelser samt hvilken indflydelse data og antagelser har på resultaterne. Yderligere følsomhedsanalyser blev tilføjet til appendix.

Efter det første kritisk review, tilføjede forfatterne yderligere specifikationer omkring materialer og mængder, justerede sprog og grammatisk fejl og tilføjede yderligere detaljer for at forbedre den overordnede forståelse af rapporten.

Executive summary - English

Conceptual framework
This study provides the life cycle environmental impacts connected to available waste management options for beverage packaging waste in Denmark in 2018. This study was carried out by DTU Environment in the period November 2017 – June 2018.

Currently, Denmark has a system under which certain beverage products (e.g. beer, carbonated soft drinks and water) may only be marketed in reusable or recyclable packaging covered by a deposit and return system. This return system for packaging waste constitutes an optimized recycling system that provides high collection efficiency (e.g. by the return of the deposit) and high quality recycling (e.g. by selectively operating within food-quality packaging material). Further room for improvement of the current recycling of beverage products can be found in other products that are not yet covered by the deposit and return system. The return system is based on product type (e.g. carbonated drink or water), rather than on material type, and other beverage packaging products not yet included in the return system, such as juice, milk, and other non-carbonated soft drinks, may be composed of the same material of those already included in the current return system.

The aim of this study is to assess the environmental impacts of alternatives for the management of beverage packaging waste. The project compares the environmental performance of the following options:
- High quality recycling via the deposit and return system;
- Collection, sorting and recycling via the existing system for recyclables;
- Incineration within the residual waste stream.

The project only investigated the recyclable packaging materials. The comparison was done for the following beverage packaging materials:
- Plastic: polyethylene terephthalate (PET) and high-density polyethylene (HDPE);
- Glass: clear, green and brown;
- Metal: aluminium;
- Composite: carton containers (75 %) with aluminium (5 %) and plastic (20 %) foil (e.g. Tetra Pak).

The goal of the assessment is to:
- Assess the environmental impacts associated with three management options for beverage packaging waste, based on the material of the packaging, for a range of environmental indicators
- Identify the management option with the lowest potential environmental impact, among the available ones, for each type of beverage packaging material for each of the environmental indicators

Methodological framework
The environmental assessment of the management options for beverage packaging waste was carried out with Life Cycle Assessment (LCA), a standardized methodology for quantifying environmental impacts of providing, using and disposing of a product or providing a service throughout its life cycle (ISO, 2006). LCA of waste management systems takes into account the potential environmental impacts associated to the disposal of the product, as potential impacts connected to material and energy required to treat the waste, and potential direct emissions. When material and energy resources are recovered, the system is credited with the

avoided potential emissions that would have been necessary in order to produce these resources.
Since beverage packaging waste can occur in different materials (e.g. plastic, glass, aluminium, carton and composite), the LCA assessed the environmental impacts connected to the management of each of three waste management alternatives, as illustrated in Figure I, for one material at a time (mono material).

The functional unit chosen for this study was:
"Management of beverage packaging waste (mono material) generated in Denmark in 2017 and not currently included in the deposit and return system. Waste management occurs partly in Denmark, and partly in other European countries."

The reference flow chosen for this study was:
"1 ton of beverage packaging waste (mono material)".

The modelling of recycling took into account the purity of beverage packaging material in the reference flow (as percent impurities in the beverage packaging material), the sorting efficiency, the technological efficiency of the recycling process (A) and the market response for the recycled material (B). The factors A and B were defined as:

- **A: Technological efficiency**
  Account for material losses during reprocessing:

$$A\ (\%) = \frac{\text{Material reprocessed (kg)}}{\text{Total material sent to recycling (kg)}} \qquad \text{(Eq.1)}$$

- **B: Market response**
  Account for the percent substitution of avoided primary material, this value indicates the extent of the material substitution in the market obtainable from the recycled material:

$$B\ (\%) = \frac{\text{Material avoided in the market (kg)}}{\text{Total reprocessed material (kg)}} \qquad \text{(Eq.2)}$$

The total recycling efficiency of the recycling process was thus given by:

$$\text{Recycling efficiency (\%)} = A \cdot B \qquad \text{(Eq.3)}$$

The total amount of recycled material from the initially collected material was calculated from Eq. 3 taking into account also the purity of the material (e.g. presence of impurities), the sorting efficiency and the market response as follows:

$$\text{Total substituted material (kg)} = \text{Reference flow (kg)} \cdot \text{Purity (\%)} \cdot \text{Sorting (\%)} \cdot \text{Recycling efficiency (\%)} \qquad \text{(Eq. 4)}$$

To illustrate what the effect of a change of the disposal of the monomaterials would be, an illustrative scenario was carried out, where a comparison was made between the current management of these materials against their disposal via the return system. The proposed expansion of the return system would not cover composite materials; as beverage products can be marketed in this type of packaging, the implementation of the new system could induce an increase use of composite packaging. To assess the effects of this, a hypothetical scenario was also modelled, where 50 % of the packaging that should be disposed by the return system was instead produced in composite materials which can not be disposed of in the return system, and therefore will be incinerated. All scenarios were based on the monomaterials, and hence do not include the production of the materials; the results can therefore not be used to decide which material that is the best packaging material.

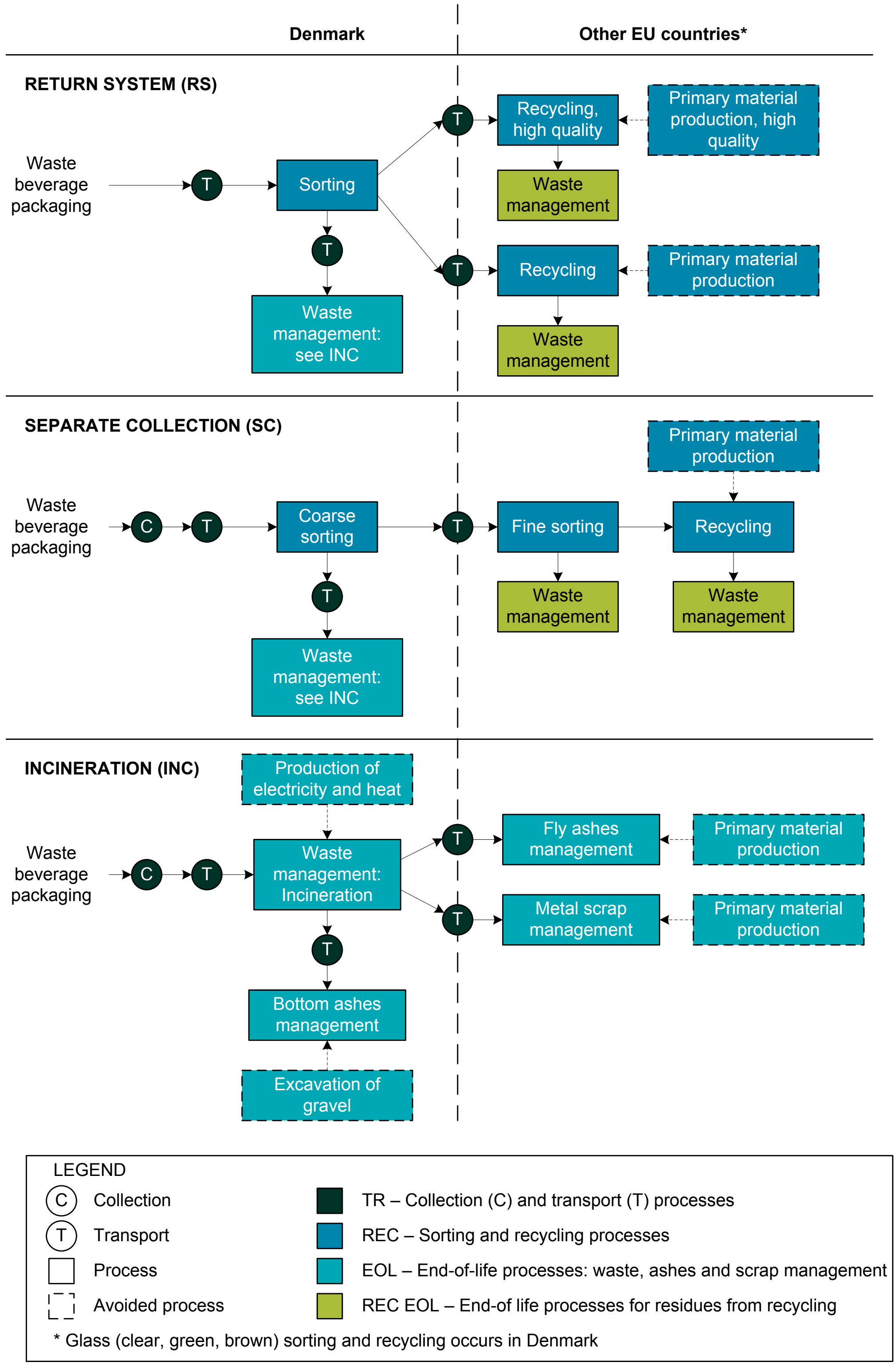


Figure I. General structure of the three end-of-life scenarios assessed. The waste management processes occur partially in Denmark, partially abroad in other European countries, with exception of glass that fully happens in Denmark.

Findings and recommendations

The deposit and return system allowed higher collection efficiencies, as well as material recovery, than the separate (municipal) collection and recycling system. Moreover, food-grade materials recovered through the return system allow for higher quality recycling. Figure II illustrates the amounts of recycled material of high quality and normal quality, as well as amounts of generated waste, for each beverage packaging material type for the return system and the separate collection scenarios. PET, glass, and aluminium were the materials with the highest recovery via the return system. The recovery efficiency of the return system was always higher than the recovery efficiency of the separate collection for the same beverage packaging waste material.

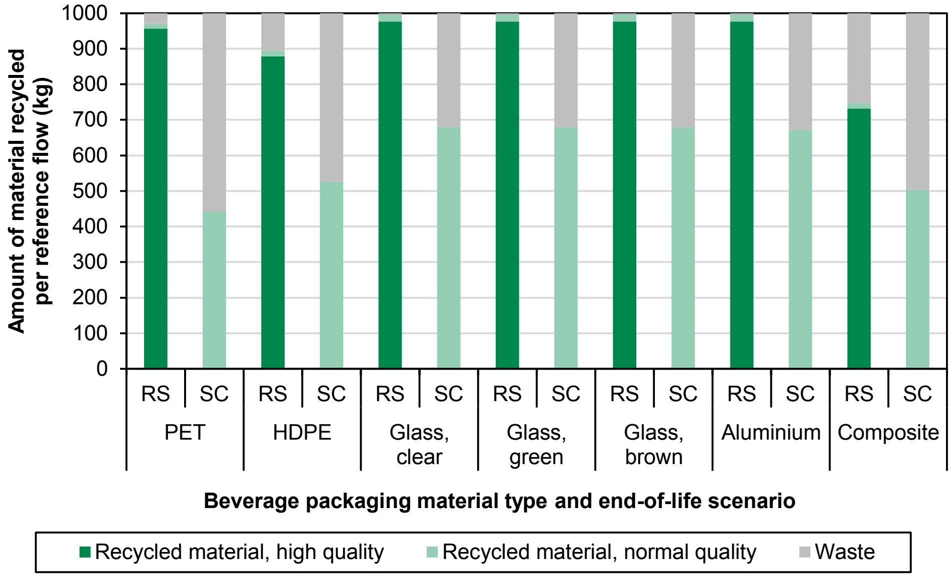


Figure II. Amounts of material recycled with high quality and normal quality, as well as amounts of generated waste, for each beverage packaging material type and the return system (RS) and separate collection scenarios (SC). Results are provided per monomaterial reference flow.

Which disposal option provides the lowest impact for each specific monomaterial beverage packaging types?

Considering climate change, the return system provided the lowest impacts for all materials. For PET and aluminium, the return system provided lowest environmental indicators for respectively 11 and 10 of the assessed environmental indicators, where it for glass was the case for all environmental indicators. For HDPE and composite beverage packaging materials, incineration resulted being the waste management solution providing the lowest impacts for a number of the environmental indicators. This was due to the comparatively lower environmental benefits connected to the recycling of these materials, due to lower reprocessing rates and lower environmental impacts from virgin production. It is important to mention that, in all the impact categories where the return system was better than incineration, the second best disposal option was separate collection.

What are the impacts connected to the production of the beverage packaging materials?

The LCA results for the best disposal option differed in magnitude because materials with high environmental production impacts are associated with high benefits when recycled. For this reason, we compared the LCA results with the impacts connected to the production of the different beverage packaging materials. Aluminium was found to be the material with the highest overall impacts, why it gives the largest savings per ton when recycled. PET have higher material production cost than HDPE, why this also leads to the higher savings when recycled. Glass is per tonne the material with the lowest impact. These values should though not be used alone, but always be considered in relationship to the amounts of the different materials that are being disposed. Finally they can not be used for identifying directly which material should be preferred in the production phase, as it only includes the production of the material itself and not other functionalities.

What are the effects of disposing beverage packaging materials via the return system in Denmark?
The illustrative scenario examples indicated that managing all waste by the return system (with the current efficiencies) would lead to improvements in 13 out of 14 impact categories, in comparison to the scenario with disposal via separate collection as it is the case today. The scenarios also showed that, if composite materials are used in some packaging to avoid being managed in the return system, the improvement in environmental impacts from the disposal of the packaging would not be as high, because the composite materials are currently not managed by the return system, nor collected for recycling in any Danish municipalities.

Summary of the critical review

Reviewers
A critical review according to ISO 14040/14044 was performed by Line Geest Jakobsen and Trine Lund Neidel from COWI A/S in March 2018.

Review process
The review process involved the following phases:
- COWI conducted the first review in March 2018.
- DTU answered to the questions raised by COWI and corrected the report according to the outcomes of the review in March 2018.
- COWI evaluated the corrections and compiled a final review statement.

The critical review from COWI can be found in full in Appendix E in form of a table with comments and replies. The main points highlighted in the critical review are provided below.

The LCA report has been reviewed with respect to compliance with the ISO 14040 and 14044 International Standards. The report was found to comply with the standards to a large extent. The authors state that the report does not comply with the standard because an exchange with a panel of experts was not made during the project phases. A stakeholder meeting was held to get comments and critique to the work, but not an actual panel of experts.

The critical review highlighted, that it had to be clear which materials was included, and that it only considered recyclable packaging, and not reuseable. Furthermore it was requested to clearly describe which amounts and materials are included in the report. Finally it was underscored that it is important with descriptions around the role quality of materials play, where additional text was added. Additional sensitivity analysis was also requested. The authors added dedicated sections on data quality assessment, critical assumption and on the influence on data and assumptions on the results. Additional sensitivity analysis was added in appendix.

After the review, the authors added further specifications on the materials and amounts, adjusted language and typos, and added further details for improving the overall understanding of the report.

Preface

This study provides the life cycle environmental impacts associated with available options for the management of beverage packaging waste in Denmark in 2018.

The commissioner of the LCA is the Danish Environmental Protection Agency (Miljøstyrelsen). The LCA was conducted by DTU Environment in the period November 2017 – March 2018, using the EASETECH LCA model developed by DTU Environment for the environmental assessment of waste management systems and environmental technologies. The assessment focuses on beverage packaging waste that is currently not covered by the Danish deposit and return system.

The LCA has been conducted according to the requirements outlined in DS/EN ISO International Standards 14040 and 14044; however, the report is not intended to strictly comply with the standard. The report is intended for internal decision support at the Danish Environmental Protection Agency as part of a wider range of assessments aiming at investigating management options for beverage packaging waste currently not part of the deposit and return system. The report has undergone peer review outside the project group by COWI A/S.

The report was prepared by Valentina Bisinella, Paola Federica Albizzati, Thomas Fruergaard Astrup and Anders Damgaard from DTU Environment.

DTU, June, 2018.

List of Abbreviations

General

A	Technological efficiency of a recycling process
B	Market response for the reprocessed materials
HDPE	High-density polyethylene
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
PE	Persons equivalents (normalized LCA results)
PET	Polyethylene terephthalate

Assessed scenarios: beverage packaging

Aluminium	Metal beverage packaging scenario; the metal is aluminium
Glass, brown	Glass beverage packaging scenario; the glass is brown glass
Glass, clear	Glass beverage packaging scenario; the glass is clear glass
Glass, green	Glass beverage packaging scenario; the glass is green glass
HDPE	Plastic beverage packaging scenario; the plastic material is high-density polyethylene
PET	Plastic beverage packaging scenario; the plastic material is polyethylene terephthalate
Tetra Pak	Composite beverage packaging scenario; the composite material is constituted of cardboard, aluminium and plastic foil

Assessed scenarios: waste management options

INC	Incineration, end-of-life scenario
RS	Return system, end-of-life scenario
SC	Separate collection, end-of-life scenario

Acronyms for the impact categories assessed by the LCA

CC	Climate change
OD	Ozone depletion
HTc	Human toxicity, cancer effects
HTnc	Human toxicity, non-cancer effects
POF	Photochemical ozone formation
IR	Ionizing radiation
PM	Particulate matter
TA	Terrestrial acidification
TE	Terrestrial eutrophication
ME	Marine eutrophication
FE	Freshwater eutrophication
ET	Ecosystem toxicity
RDfos	Resource depletion, fossil
RD	Resource depletion, abiotic

Key definitions

A	**Technological efficiency of a recycling process** Takes into account of the material losses during reprocessing. It is provided as a percentage and it is used to calculate the amount of reprocessed material from a recycling process, as well as the resulting amount of residues. $A\ (\%) = \frac{\text{Material reprocessed (kg)}}{\text{Total material sent to recycling (kg)}}$ Ex/ If A=75 %, it means that 75 % of the collected beverage packaging waste is reprocessed to recycled material, while 25 % of the collected beverage packaging waste ends up as residue.
B	**Market response** Takes into account the percent substitution of primary material in the market that can be obtained with the reprocessed material from a recycling process (see A). The market response is given as a percent and allows calculating the amount of avoided production of primary material. $B\ (\%) = \frac{\text{Material utilized in the market (kg)}}{\text{Total reprocessed material (kg)}}$ Ex/ if B=81 %, it means that 81 % the recycled material from beverage packaging waste will replace primary material in the market, thus avoiding its production and related impacts.

1. Introduction and objectives

This study was commissioned by the Danish Environmental Protection Agency (Miljøstyrelsen) in order to assess the life cycle environmental impacts associated with the management options for beverage packaging waste in Denmark in 2018. This section provides the background on beverage packaging waste in Denmark and the aim of the study.

1.1 Background

The resource strategy “Danmark uden affald” developed by the Danish Environmental Protection Agency for waste management in Denmark focuses on the importance of considering waste as a resource (Miljøstyrelsen, 2014). The strategy follows the European Directives on prioritizing prevention, reuse and recycling over incineration and landfilling (European Commission, 2008). In particular, the key priority area of the strategy is increasing recycling in Denmark, by supporting the development of new collection schemes, by developing better sorting and treatment facilities and, most importantly, by prioritizing quality in recycling. Within the household and service sectors, the strategy dedicates a special focus on packaging and packaging waste. The strategy indicates beverage packaging as an area with potentially high amounts of waste, as well as characterized by a high recovery potential due to relative homogeneous composition of the beverage packaging in comparison to other packaging types. Currently, Denmark has a system under which certain beverage products (e.g. beer, carbonated soft drinks and water) may only be marketed in refillable packaging or disposable packaging covered by a deposit and return system, which is driven by the producers for refillable packaging, and by Dansk Retursystem A/S for recyclable packaging. Empty refillable packaging must be returned to stores, where they are reused by refilling and, when a refillable packaging can no longer be reused, the materials are recovered for recycling. Empty disposable packaging must be returned to shops where they are collected for recycling of the material, in exchange for the paid deposit. In accordance with the resource strategy, this return system for disposable packaging waste constitutes a potentially optimized recycling system that provides high collection efficiency (e.g. by the return of the deposit) and high quality recycling (e.g. by selectively operating within food-quality packaging material).

Further room for improvement of the current recycling of beverage products can be found in other products that are not yet covered by the deposit and return system. Indeed, the packaging waste currently managed within the deposit and return system is based on product type (e.g. carbonated drink or juice produced by a specific brand), rather than on material type. For this reason, other beverage packaging products not yet included in the return system, such as juice, milk, and other non-carbonated soft drinks, may be composed of the same material as those already included in the current return system. Currently, the management options for these beverage packaging waste are source segregation and recycling within the existing system for recyclables (mixed packaging material and potentially lower quality recycling, non-food-quality), or incineration within the residual waste stream.

1.2 Aim of the study

The aim of this study is to assess the environmental impacts associated with alternative management options for beverage packaging waste from the beverage products that are not currently part of the Danish deposit and return system. In line with the resource strategy, the project wishes to compare the environmental performance of:

- High quality recycling via the deposit and return system;
- Collection, sorting and recycling via the current system for recyclables;

- Incineration within the residual waste stream.

The project will consider that the deposit and return system is expected to have higher collection efficiency due to the return of the paid deposit, as well as a higher quality recycling. The beverage packaging materials investigated will be plastic, glass and aluminium. Moreover, since the deposit and return system is based on specific products, the potential introduction of new beverage products in the system may result in a shift to other beverage packaging material from the producers' side. For this reason, the project also investigates additional management scenarios for composite (e.g. Tetra Pak) beverage packaging materials. These materials will be investigated for all management scenarios, even if they are not currently comprised in the materials allowed by the return system.

The goal of the assessment is to:

- Assess the environmental impacts associated with three management options for recyclable beverage packaging waste, based on the material of the packaging, for a range of environmental indicators
- Identify the preferable management option among the available ones, for each type of beverage packaging material for each of the environmental indicators;

The environmental assessment of the management options for beverage packaging waste is carried out with Life Cycle Assessment (LCA), a standardized methodology for quantifying environmental impacts of providing, using and disposing of a product or providing a service throughout its life cycle (ISO, 2006). LCA of waste management systems takes into account the potential environmental impacts associated to the disposal of the product, as potential impacts connected to material and energy required to treat the waste, and potential direct emissions. When material and energy resources are recovered, the system is credited with the avoided potential emissions that would have been necessary in order to produce these resources. The LCA will be carried out with the EASETECH model developed at DTU Environment (Clavreul et al., 2014). The goal definition of the LCA and the LCA methodology are provided in a dedicated section.

The results of the project aim to provide information that allow discussing and ultimately supporting decisions regarding the future management of beverage packaging products on the Danish market that are not currently part of the deposit and return system. The included discussions are based on the LCA results and focuses on the potential for expanding the return system to new product groups.

The present study considers the main types of beverage packaging available for purchase in Denmark in 2017. Instead of considering the specific beverage products, this study focused on the beverage material and on the potential environmental impacts associated to its end-of-life.

To support the discussion on the management of the individual mono materials, two subchapters were included in the discussion chapter, to contextualize what the effect of changes to the management of the beverage packing materials can have. The first subchapter compares the results with the impacts from the original production of the material (impacts from the production of the material itself and not manufacturing of the beverage packaging product), to illustrate the magnitude of these impacts in comparison with the waste management of the material. The second subchapter includes illustrative scenarios for what a shift from the current management of the packaging, to a system where the beverage types are included in the return system, based on current amounts and management of the beverage packaging. The study did not include specific effects of taxation or behavioural changes. However, the illustrative scenarios include an example on what the effect could be, if the change to the return system would make some producers change their material to carton and composite containers, which are not included in the proposed materials to be included in the return system, and therefore would be disposed with residual waste.

2. Beverage packaging waste

The current Danish fee-based system for beverage packaging consists of two sub-systems. The first involves refillable packaging that is returned to the producers for refilling a large number of times (i.e. beer and soda bottles in glass), while the second consists of recyclable packaging that is collected by Dansk Retursystem A/S, which sorts it and sends it for recycling into new food grade materials. This study will focus on the expansion of the return system for disposable packaging to cover a new range of juice and milk products that are currently not included in the system. Dansk Retursystem A/S is currently handling packaging of carbonated soft drinks and carbonated alcoholic drinks as well as bottled water which is sold in Denmark. The definition of juice products cover beverages falling within the EU Combined Nomenclature position 2009, i.e. products made of pressed fresh fruits or vegetables. In the report we have split the juice into juice ready for direct consumption, and concentrated juice that is to be mixed with water before consumption (this also includes non-carbonated concentrated soft drinks that is outside the definition of 2009). Milk products are beverages containing milk which are immediately ready for drinking and are classified under heading 2202 of the EU Combined Nomenclature, e.g. cocoa milk, chocolate milk and iced coffee. The proposed expansion will focus on products which are collected for recycling, meaning that this study only includes an assessment of materials collected for recycling, and not for direct reuse.

2.1 Beverage packaging types

Dansk Retursystem A/S is currently handling packaging of carbonated soft drinks and carbonated alcoholic drinks as well as bottled water which is sold in Denmark. The type of packaging that is covered by the system is set by law, and therefore it only covers packaging products meant for recycling and not reuse, sold in the following materials:

- Plastic bottles
- Aluminium beverage cans
- Glass bottles

Beverage products that fall within these types but which are sold in other packaging types and which are not recovered by the return and deposit system:

- Composite containers: 75 % cardboard, 20 % Plastic foil (PE), 5 % aluminium.

2.2 Beverage packaging amounts in Denmark

Dansk Retursystem A/S collected 48.000 tons of packaging for recycling in 2016 (Dansk retursystem, 2016).The system collected circa 90 % of the fee based packaging, which means that approximately 5.300 tons was handled by the traditional recycling system or incineration of residuals.

A survey by The Nielsen Company (2018) of drinking packaging in use in Danish retail sector covering the three proposed product groups to be included, reported the amounts of juice (ready to drink and juice to mixed with water) and milk products in pieces (1000´s) in Table 1, and weight in Table 2. The values are calculated as aggregated amount from specific products sold in Danish retail stores to the 3 packaging types, for the three product types combined and separately.

Table 1: Amount of plastic, glass and aluminium packaging used for juice and milk products currently on the market. Juice is split in ready to drink, and juice that must be mixed with water. Data are based on The Nielsen Company (2018) for individual products on use in the Danish market aggregated to total amount in 1000 pieces.

	Year	Plastic – HDPE*	Plastic – PET*	Glass	Aluminium	Total
		Pieces - 1000's	Pieces - 1000's	Pieces - 1000's	Pieces - 1000's	Pieces - 1000's
Total - Milk and Juice products	2017	21 415	21 415	17 450	4 925	65 204
	2016	19 114	19 114	18 118	3 925	60 270
	2015	17 503	17 503	12 458	3 436	50 899
Juice products – Ready to drink	2017	12 030	12 030	3 630	1 566	29 255
	2016	10 565	10 565	3 272	654	25 056
	2015	8 448	8 448	2 149	557	19 602
Juice products – To be mixed	2017	8 431	8 431	5 943	0	22 879
	2016	7 823	7 823	6 764	0	22 409
	2015	8 468	8 468	6 119	0	22 980
Milk products	2017	955	955	7 701	3 359	12 969
	2016	726	726	8 082	3 271	12 805
	2015	587	587	4 366	2 879	8 418

* The split between PET and HDPE was not available in the Nielsen Company data, so the plastic was assumed split 50/50.

The values in Table 1 were converted to total weight by combining information on the volume for the individual products in the Nielsen data, with an average weight per cl for the four packaging types. The average weights were found by weighing a number of juice and milk containers from Danish Supermarkets. The following weight conversions were used for the total amount presented in Table 2:

- HDPE plastic: 0.62 g per cl. content
- PET plastic:0.45 g per cl. content
- Glass:7.9 g per cl. content
- Aluminium: 0.69 g per cl. content
- Composite packaging: 0.40 g per cl. content

The weight for composite packaging is included to allow for comparison in Section 7, but is not used further in this section.

Table 2. Amount of plastic, glass and aluminium packaging used for juice and milk products currently on the market. Juice is split in ready to drink, and juice that must be mixed with water. Data are based on Nielsen (2018) for individual products on use in the Danish market. The values have been converted to metric tons by multiplying with an average weight per volume for the different materials.

	Year	Plastic – HDPE*	Plastic –PET*	Glass	Aluminium	Total
		ton	ton	ton	ton	ton
Total - Milk and Juice products	2017	1 033	750	8 245	83	10 027
	2016	920	668	8 591	74	10 178
	2015	864	627	5 985	64	7 471
Juice products – Ready to drink	2017	570	413	1 765	17	2 719
	2016	483	351	1 519	8	2 322
	2015	393	285	1 084	8	1 738
Juice products – To be mixed	2017	444	323	2 479	0	3 210
	2016	419	304	2 899	0	3 588
	2015	455	330	2 604	0	3 353
Milk products	2017	19	14	4 001	67	4 098
	2016	17	13	4 173	66	4 268
	2015	16	12	2 297	56	2 379

* The split between PET and HDPE was not available in the Nielsen Company data, so the plastic was assumed split 50/50 in amount pieces, and then based on weight per piece.

The data on the number of individual pieces of packaging (Table 1) show that juice products dominate the market with about 4 times as many items compared to milk products. The above results look rather different considering the weight of the individual packaging types, as the glass bottles are much heavier, and comparing the total weight they have there are therefore a large weight share of packaging products for the milk products. The combined weight for 2017 is 10 027 tons, with 9% from milk products and 12% from juice products. The data shows that for glass there is even distribution between milk and juice products, and for aluminium the milk products have the largest share, whereas for juice products plastic dominates. The large increase in total weight from 2015 to 2016 is mainly due to an increase in glass packaging for milk products.

It should be noted that the data from The Nielsen Company (2018) did not include amounts from restaurants and other non-retail sector outlets, and furthermore it is not known what the distribution of the different packaging materials from these is. So the reported amounts are considered to be lower than the total potential.

2.3 Beverage packaging management in Denmark

For the material not currently part of the fee based system, the waste handling is managed together with the rest of the generated household waste. This information is relevant as some materials are already collected for recycling via municipal collection schemes, and the rest is disposed of with the residual waste. Table 3 shows values for packaging materials collected for recycling in 2014 and 2015 based on data from Miljøstyrelsen (2018), which are the most recently available. The values in Miljøstyrelsen (2018) include materials already being collected by Dansk Retursystem. The data from Miljøstyrelsen (2018) were therefore recalculated by subtracting the materials collected by Dansk Retursystem A/S (2015, 2016). The values including materials collected by Dansk Retursystem are given in parenthesis in Table 3, and show that existing materials already a part of the return system make up a considerable share of the overall recycling. It also shows that that for glass and metals the difference between the fee based system with a 90% efficiency, and the normal collection system is in the order of 25-40%, , whereas for plastic there is a large difference of 67 % in what is collected. It should be noted that these values only represent the collected amounts, whereas the losses in the consecutive sorting is considerably higher for the non-fee based system, due to the more heterogeneous material being collected.

Table 3. Percent of packaging material collected for recycling in Denmark, excluding material collected via the return system. Values for 2014 and 2015 from Miljøstyrelsen (2018). In parenthesis is given total values including amount collected via the current return system.

Material	Collected for recycling	
	2014	2015
Plastic	23 % (31 %)	23 % (30 %)
Metal (Aluminium and Iron)	47 % (67 %)	50 % (72 %)
Glass	71 % (84 %)	66 % (79 %)

If all the products included in Table 2 were to be included in the return system, with 90% collection efficiency, this would mean that approximately an additional 9000 tons of packaging waste would be collected by Dansk Retursystem A/S, which corresponds to an increase of 19% of their current management.

3. LCA Methodology

The LCA carried out for this study was conducted according to the requirements outlined in the International Standards 14040 and 14044 (ISO, 2006a, 2006b). The present section provides a detailed description of the LCA methodology utilized for the study: the goal of the LCA, functional unit and reference flow, the system boundaries, the choices for the modelling approach for addressing multi-functionality, the modelling tools, data requirements, impact assessment method, assumptions and limitations.

The final receiver of the study is the Danish Environmental Protection Agency and the study might ultimately be used for internal decision support at the Danish Environmental Protection Agency as part of a wider range of assessments aiming at investigating possible management options for beverage packaging waste, or be disclosed to third parties. The report has undergone external peer review by COWI A/S, but not by a panel of experts throughout the development of the project. For this reason, the report is not strictly complying with the standard.

The project did not focus on extensive data collection and was intended to be based on existing inventories for resources and data in the literature. Therefore, most of the life cycle inventory (LCI) data used was based on publicly available LCI data and data from existing LCA studies on beverage packaging waste.

3.1 LCA goal definition

The goal of this study was to provide the Danish Environmental Protection Agency with the potential life cycle environmental impacts associated with three management options for Danish beverage packaging waste. The aim of the study was to:

I) Assess the environmental impacts associated with three management options of beverage packaging waste, based on the material of the packaging, for a range of environmental indicators. The three waste management options were:

- Collection and fine sorting within the return system, with high quality recycling;
- Source segregation within recyclables and collection by the Danish waste management system, sorting and recycling;
- Collection in the residual waste stream of the Danish waste management system, incineration.

II) Identify the most preferable waste management option between the ones assessed, for each type of beverage packaging material and over a range of environmental indicators.

3.2 Functional unit

The functional unit chosen for this study was:
"Management of beverage packaging waste (mono material) generated in Denmark in 2017 and not currently included in the deposit and return system. Waste management occurs partly in Denmark, and partly in other European countries."

Since beverage packaging waste can occur in different materials (plastic, glass, aluminium, carton and Tetra Pak), the LCA assessed the environmental impacts connected to the management of each of the alternatives for one material at a time (mono material). It is assumed that the recycled material competes only with virgin or recycled material of the same type. The scenarios are described in detail in Section 4. The functional unit defined for this study did not cover prevention strategies, nor consumer behaviour or behavioural changes.

3.2.1 Reference flow

The reference flow chosen for this study was:
"1 ton of beverage packaging waste (mono material)".

The beverage packaging materials examined were: plastic (PET, HDPE), glass (clear, green and brown), aluminium, and composite (such as Tetra Pak and similar).

The reference flow for the beverage packaging material differed according to their physico-chemical material composition. Further details are provided in the Life Cycle Inventory (LCI; Appendix A).

3.3 System boundaries

The time horizon of the impacts in this LCA was 100 years. The geographical scope was Europe. The temporal scope was 2018. The study assessed the life cycle environmental impacts associated with available management options at the beginning of 2018 for beverage packaging waste. This assessment was based on available data on amounts and composition of beverage packaging waste by the end of 2017. Therefore, the functional unit and reference flow refer to "2017". The LCA was a "gate-to-grave" LCA, meaning that the primary focus of the LCA was to evaluate the environmental impacts of the waste management phase of beverage packaging products.

The system boundaries included collection of beverage packaging waste, treatment and management of the treatment residues. The boundaries included emissions to air, water, and soil occurring during the management of the waste. The assessment included the impacts connected to the production of materials and energy resources required for the treatment of the beverage packaging waste (such as electricity and ancillary materials), as well as the fuel used for transportation between the waste treatment stages. The assessment took into account the emissions avoided by the recovery of materials and energy during the management of beverage packaging waste. For example, this means that recovering an amount of aluminium from beverage cans allowed avoiding an amount of primary aluminium production and related impacts. The amount of recovered and avoided aluminium is determined by the system model, based on technological efficiency and market response. Details and methodology are provided in Section 3.8 on modelling of recycling processes.

The waste management processes were set to occur partly in Denmark (collection, transport, fine sorting in a return system facility, coarse sorting of source segregated fractions and incineration) and partly in other European countries (transport, further sorting of source segregated fractions, recycling and final disposal of rejects from sorting facilities not located in Denmark). Collection, transport, sorting, recycling and disposal of rejects from glass packaging waste were all set to occur in Denmark.

Capital goods, i.e. the construction of facilities and the production of machineries and transport vehicles, were not included in the assessment as the waste flows were assumed to be managed within existing capacities, and that any changes to these flows were considered marginal for the involved capacities. The LCA for the mono materials did not consider behavioural changes or consequences of introduction of taxation. The environmental assessment did not take into account the effects of littering. Biomass was not considered a limited resource for biomass energy, as it was assumed based on residual biomass. Indirect land use changes were included for the composite packaging.

3.4 Modelling approach and allocation of multi-functionality

The present study aims at assessing the environmental impacts associated with potential in the management of beverage packaging waste and may be used for decision support. For these reasons, the modelling approach used for this study was consequential LCA. The LCA applied system expansion, meaning that the LCA took into account additional functions arising from the treatment of beverage packaging waste, such as recovered energy and secondary raw materials.

Such multi-functionality was addressed in the model by system expansion. This means that recovered energy and materials generated along with the main service provided by the scenarios, i.e. treatment of the beverage packaging waste, were assumed to displace those products in the market that were likely to react to changes in demand/supply induced by the investigated scenarios. These technologies were referred to as “marginal technologies” and are discussed in detail in Appendix B. Examples are the energy produced from the incineration of the waste, and recovered material from the recycling processes.

The marginal energy technologies were selected in accordance with the project partners and are described in detail in Appendix B. In accordance with the Danish Environmental Protection Agency and the Danish Energy Agency, the marginal energy technologies used for this project were based on the latest published project from the Danish Environmental Protection Agency, which provided marginal energy technologies for electricity and heat: TemaNord 2016:537 - Gaining benefits from discarded textiles - LCA of different treatment pathways, published by the Nordic Council of Ministers (Schmidt et al., 2016). The marginal energy technologies have a future outlook and were defined for the period 2020 – 2030. Since the study may support decisions that will occur e.g. in a 10 year period, using a future marginal energy was assumed to appropriately represent the effects of such choices in the future waste management system.

3.5 Modelling tools

The study was carried out with the waste-LCA model EASETECH (Clavreul et al., 2014), which was developed at DTU Environment and used for this assessment. EASETECH allows modelling of the flow of material in the LCA as a mix of material fractions (e.g. plastic, paper) and tracking their physico-chemical properties (e.g. energy content, fossil carbon) throughout the modelled life-cycle steps. The tracking of the material composition on top of the conventional mass flow-based LCA allows expressing consumption and production of resources based on the physico-chemical properties of the functional unit, and especially to express emissions to air, water and soil occurring during the end-of-life phases as a function of its chemical composition (e.g. fossil carbon emitted during incineration).

3.6 LCIA methodology and types of impacts

The impact categories for the impact assessment phase were selected on the basis of the ILCD recommended impact factors by the European Commission (2010). Since the LCA study may be used to support decisions, a comprehensive set of indicators were provided. No weighting of the LCA results was included. The selected impact categories were: climate change, ozone depletion, human toxicity cancer and non-cancer effects, photochemical ozone formation, ionizing radiation, particulate matter, terrestrial acidification, terrestrial eutrophication, freshwater eutrophication, ecosystem toxicity, resource depletion, fossil and abiotic. Results are presented as characterized impacts following the characterization references in Table 4.

Table 4. Characterization references (midpoint) utilized in the project. The impact category "Depletion of abiotic resources" follows the ILCD recommended characterization factors.

Impact category	Acronyms	LCIA method	Reference year	Units
Climate change	CC	ILCD2011, Climate change w/o LT; midpoint; GWP100; IPPC2007	2011	kg CO_2 eq.
Ozone depletion	OD	ILCD2011, Ozone depletion w/o LT, ODP w/o LT	2011	kg CFC-11 eq.
Human toxicity, cancer effects	HTc	ILCD2011, Human toxicity, cancer effects, w/o LT, USEtox	2011	CTUh
Human toxicity, non-cancer effects	HTnc	ILCD2011, Human toxicity, non-cancer effects w/o LT, USEtox	2011	CTUh
Particulate matter/Respiratory inorganics	PM	ILCD2011, Particulate matter w/o LT, from Humbert 2009, PM	2011	kg PM2.5 eq.
Ionizing radiation, human health	IR	ILCD2011, Ionising radiation human health w/o LT, IRP100 w/o LT, ReCiPe 1.05 midpoint (H)	2011	kBq U235 eq. (to air)
Photochemical ozone formation, human health	POF	ILCD2011, Photochemical ozone formation, human health w/o LT, POCP	2011	kg NMVOC eq.
Terrestrial acidification	TA	ILCD2011, Terrestrial acidification, Accumulated Exceedance	2011	mol H+ eq.
Eutrophication terrestrial	TE	ILCD2011, Eutrophication Terrestrial, Accumulated Exceedance	2011	mol N eq.
Eutrophication freshwater	FE	ILCD2011, Eutrophication Freshwater, FEP ReCiPe 1.05 midpoint (H)	2011	kg P eq.
Eutrophication marine	ME	ILCD2011, Eutrophication Marine w/o LT, ReCiPe2008 1.05	2011	kg N eq.
Ecotoxicity freshwater	ET	ILCD2011, Ecotoxicity freshwater w/o LT, USEtox	2011	CTUe
Resources, depletion of abiotic resources, fossil	RDfos	CML 2001, Depletion of abiotic resources, fossil - updated 2016	2016	MJ
Resources, depletion of abiotic resources, elements (reserve base)	RD	CML 2001, Depletion of abiotic resources, elements (reserve base) - updated 2016	2016	kg Sb eq.

3.7 End-of-life scenarios assessed

The scenarios assessed in this LCA study were the result of a combination of each of the selected beverage packaging materials with each of the following end-of-life options: collection and recycling within the return system, collection and recycling with the source segregated waste, and incineration.

The beverage packaging materials selected were the following: plastic (PET and HDPE), glass (clear, green and brown), metal (aluminium), composite (as juice cartons, Tetra Pak). The packaging material types and scenario names are summarized in Table 5.

Table 5. Packaging material types selected for this LCA study and corresponding scenario name.

Packaging material type	Sub-type	Scenario name
Plastic	PET	PET
Plastic	HDPE	HDPE
Glass	Clear glass	Glass, clear
Glass	Green glass	Glass, green
Glass	Brown glass	Glass, brown
Metal	Aluminium	Aluminium
Composite	Carton containers, Tetra Pak	Composite

For each packaging material type, the LCA assessed the impacts connected to the management of the reference flow (1 ton of mono-material beverage packaging waste) with each of the three end-of-life options, as if all beverage packaging waste materials was treated with only one management option at a time. This modelling choice allowed identifying the waste management solution providing the lowest environmental impacts for each waste beverage packaging material type. The general structure of the three end-of-life scenarios assessed is illustrated in Figure 1. The colour scale in the Figure distinguishes between the different treatment phases of the waste management system: collection and transport, sorting and recycling, treatment of residues and specific treatment of residues from recycling. As Figure 1 illustrates, the waste management scenarios are set to occur partially in Denmark, and partially in other European countries. The same colour scale used in Figure 1, was used in the later contribution analysis of the waste management phases for the results.

3.7.1 Return system (RS)

The beverage packaging waste is collected at Danish supermarkets by the return system. As described in Section 2, this assessment only considers packaging material that is collected for recycling. The collected beverage packaging is therefore transported to a sorting facility in Denmark, where the waste undergoes a fine sorting process that separates 97.7 % high quality material that can directly be used for the same type of products (food grade material), and 2.2 % material with a lower quality that is recycled into other types of products. See appendix A for more details. Rejects from sorting at Dansk Retursystem constitute 0.1% of the input amount. These sorting efficiencies were provided by Dansk Retursystem A/S (2017) and were set as equal for all collected material types. The rejects from fine sorting are incinerated in Denmark. The incineration process recovers electricity and heat, and residues from incineration are managed partly in Denmark (bottom ash is reused for road construction, avoiding the excavation of gravel), partly in other European countries (fly ash, aluminium and iron scraps are recycled). The sorted material from the return system is sent abroad to other European countries for recycling. The high quality material is recycled with high efficiency, while the material with lower quality is recycled with average recycling efficiency. The recovered secondary material with high purity is used to avoid the production of food-grade primary material of the same type, while the lower quality material is set to avoid the virgin production of material of the same type with non-food grade quality. The residues from recycling abroad are incinerated.

3.7.2 Separate collection (RS)

The beverage packaging waste is source segregated in Denmark with waste materials of the same type and collected by the separate collection scheme of the Danish waste management system. The collected waste is transported to a coarse sorting facility in Denmark, where recyclable material is separated from rejects. The rejects are incinerated in Denmark. The incineration process recovers electricity and heat, and residues from incineration are managed partly in Denmark (bottom ash is reused for road construction, avoiding the excavation of gravel), partly in other European countries (fly ash, aluminium and iron scraps are recycled). The recyclable material separated by the coarse sorting is transported abroad to other European countries, where it undergoes further fine sorting. The sorted materials are recycled, and the recovered secondary material avoids the production of virgin material of the same type. The residues from fine sorting and from the recycling process are incinerated.

3.7.3 Incineration (INC)

The beverage packaging waste is discarded in the residual waste stream of the Danish waste management system. After collection, it is transported to an incineration facility in Denmark. The incineration process recovers electricity and heat (22 and 73% efficiency respectively), and residues from incineration are managed partly in Denmark (bottom ash is reused for road construction, avoiding the excavation of gravel), partly in other European countries (fly ash, aluminium and iron scraps are recycled).

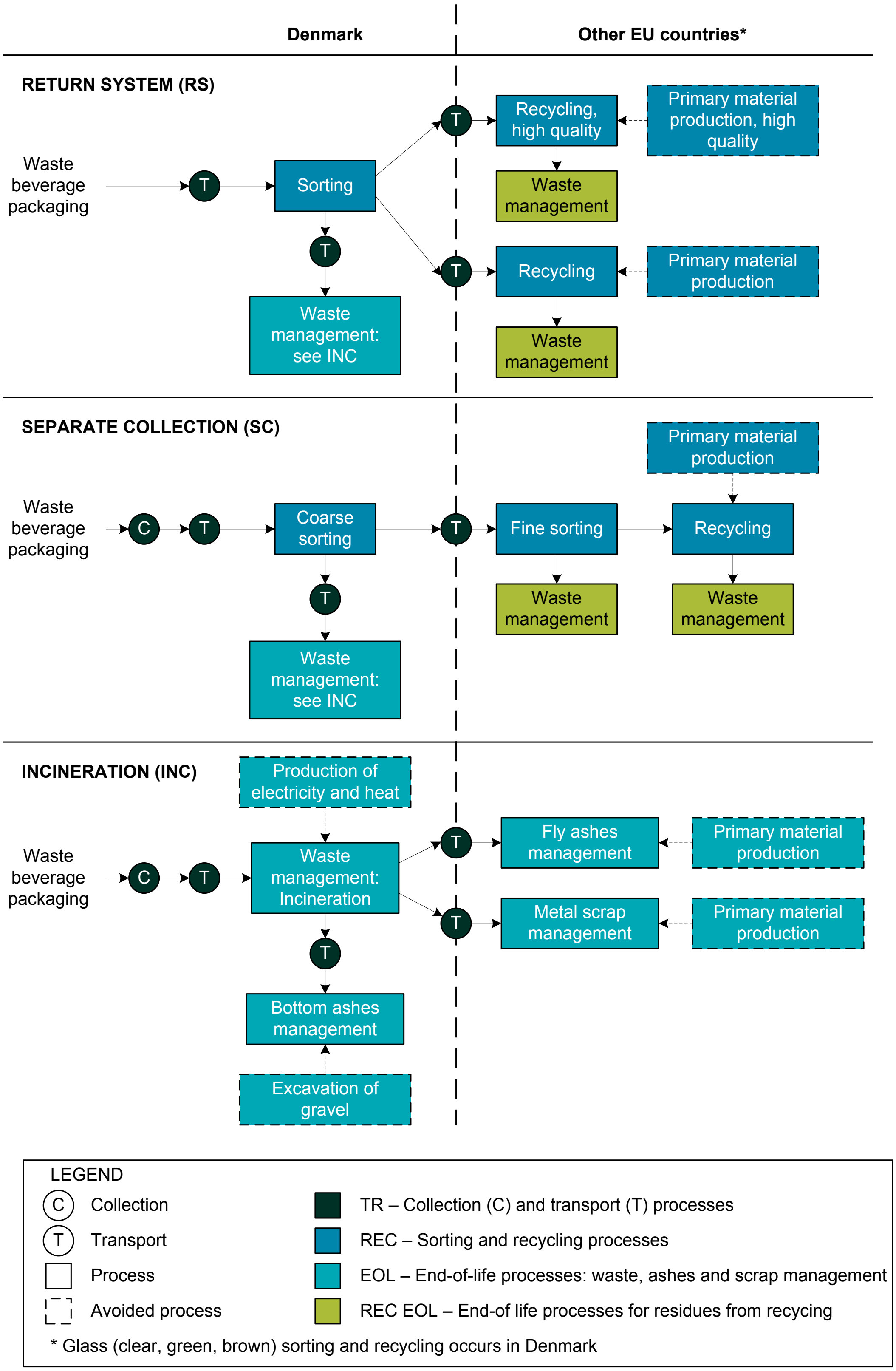


Figure 1. General structure of the three end-of-life scenarios assessed. The waste management processes occur partially in Denmark, partially abroad in other European countries, with exception of glass. The colour scale assigned to the different waste management phases is the same used for the contribution analysis in Section 6.

3.8 Modelling of recycling processes

Recycling processes in this study were modelled using the EASETECH LCA model, based on literature data. The modelling was carried out with two quality levels of recycling. “High quality” recycling, which is where the material can be directly used for the same product again (i.e. food grade plastic to be recycled into food grade plastic), and “normal quality” where the fact that materials are collected commingled with other similar materials, means that they can’t be recycled into materials with high quality requirements. Only the return system offers the traceability that allows for high quality recycling, whereas the separate collection only can be used for normal quality recycling.

On top of taking into account the amount and material composition of beverage packaging waste collected for recycling and the impacts connected to ancillary materials and energy requirements, two factors (Vadenbo et al., 2017) were considered for the modelling of recycling:

- **A: Technological efficiency**
  Takes into account material losses during reprocessing

$$A\ (\%) = \frac{\text{Material reprocessed (kg)}}{\text{Total material sent to recycling (kg)}} \qquad \text{(Eq.1)}$$

- **B: Market response**
  Takes into account the percent substitution of avoided primary material in the market

$$B\ (\%) = \frac{\text{Material avoided in the market (kg)}}{\text{Total reprocessed material (kg)}} \qquad \text{(Eq.2)}$$

The technological efficiency (A) was used to calculate the amount of high or normal quality (different factors for different qualities) material separated during reprocessing and to calculate the amount of resulting rejects. For example, if A was 75 %, it means that 75 % of the collected beverage packaging waste is reprocessed to recycled material, while 25 % of the collected beverage packaging waste ends up as a residual fraction that is incinerated. The reprocessed material then substitutes a percent of primary material in the market according to the market response (B). The market response indicates the extent of the material substitution in the market obtainable from the recycled material. For example, if B is 100 %, all the recovered material can be considered as effectively avoiding production of material from virgin resources. If B is lower than 100 % (for example 81 % in the case of PET and HDPE), it means that the recovered material still needs an additional amount of virgin material in order to reach the same functional properties.

As far as a mass balance is concerned, this does not mean that part of the recovered material goes for waste (for example 19 % for PET and HDPE). All material recovered after the technological efficiency (A) is recycled, but 19 % of it does not provide substitution of virgin material, since a corresponding amount of virgin material has to be added to reach the same functional properties (Miljøstyrelsen, 2006)

The total recycling efficiency of the recycling process is thus given by:

$$\text{Recycling efficiency (\%)} = A \cdot B \qquad \text{(Eq.3)}$$

The total amount of recycled material is thus corresponding to the overall substituted amount of material. The total amount of recycled (substituted) material can be calculated from the initially collected material using Eq. 3. This Equation takes into account also the purity of the material (e.g. presence of impurities), the sorting efficiency and the market response as follows:

Total substituted material (kg) = Reference flow (kg) · Purity (%) · Sorting (%) · Recycling efficiency (%) (Eq. 4)

The purity takes into account the amount of targeted recyclable beverage material fraction collected versus the total collected amount. For example, any impurities in the collected waste beverage packaging material, such as paper tissues or other waste would lower the purity. The sorting efficiency represents the amounts after losses from sorting of the material, prior to the actual recycling process where there can be further losses which is covered by the A factor..

3.9 Data requirements

In order to carry out this LCA study, we required data mainly on: beverage packaging waste physico-chemical characteristics (such as energy content per ton of collected waste), the fuel consumption and the distances driven during collection and transport, the sorting processes (both for the return system and the source segregated waste), the recycling processes, and the treatment of residues. Moreover, we required data on the environmental impacts connected to the production of ancillary materials and energy required for the treatment and disposal of the beverage packaging waste.

The project did not focus on extensive data collection and was intended to be based on existing and available inventories for resources and data in the literature. For this reason, the study was mostly based on data available in the Ecoinvent database, version 3.4. In order to be consistent with the modelling approach of the study, we used the consequential version of the database. Table 6 shows the availability of data from LCI databases, literature sources and EASETECH at the beginning of this LCA study. All data and details regarding the scenarios are provided in Appendix A.

- **Physico-chemical composition data**
  First of all, data on the physico-chemical composition of waste beverage packaging was retrieved from the EASETECH database and was based on the study from Riber et al. (2009). Physico-chemical composition data was available for clear, green and brown waste glass, as well as for waste aluminium beverage cans and beverage packaging waste of composite materials (carton, aluminium and plastic foil). As far as PET and HDPE were concerned, only data on generic waste plastic bottles was available.

- **Collection and transport**
  The exact distance between collection point and treatment plant was not available. Collection and transportation in Denmark to the sorting plants can occur from different locations in the country, and recycling abroad can potentially occur in different locations in Europe. In the case of the return system scenarios, collection and transport data were provided by Dansk Retursystem A/S (Dansk Retursystem A/S, 2017), which provided an aggregated average value for diesel consumed by collection and transport per ton of beverage packaging waste collected by the return system. Datasets for emissions related to collection and transportation were retrieved from the Ecoinvent database.

- **Sorting**
  For the return system scenarios, fine sorting occurred in Denmark. The sorting efficiencies and the energy consumption during the sorting process were provided by Dansk Retursystem A/S (Dansk Retursystem A/S, 2017). For the SC scenarios, sorting occurred in two stages: coarse sorting in Denmark followed by finer sorting abroad before recycling. Data on sorting efficiencies for coarse and fine sorting in Denmark of source segregated waste was available from COWI (2017). Data for fine sorting in Europe was not available.

- **Recycling**
  Data on recycling processes and efficiencies for all beverage packaging materials was available from the literature. The data was available for non-food grade processes, which we referred to as “normal quality” recycling processes. “High quality” recycling refers to the high quality material separated from the return system: the beverage packaging is collected exclusively with beverage packaging material and can be recycled into food grade material. Specific data on food-grade material was available only for PET. Data for recovered materials was obtained from the Ecoinvent database. Details on recycling and on the marginal materials are provided in Section 4 and in Appendix B.

- **Treatment of residues**
  Treatment of residues from sorting in Denmark (return system and SC end-of-life scenarios) and residual waste (INC end-of-life scenario) occurs via incineration. Incineration in Denmark was modelled with the EASETECH LCA model, as well as management of residues from the incineration process. The residues from recycling abroad were modelled with processes obtained from the Ecoinvent database.

- **Material and energy requirements**
  Ancillary materials and energy were required in all processes, for all end-of-life scenarios. Ecoinvent datasets were used for inventories for all materials and energy resources required for the management of beverage packaging waste. The database provides “market” and “production dataset” and the possibility to retrieve datasets for specific geographical locations. Usually, the impacts connected to “market” and “global” datasets provide slightly larger environmental impacts than production datasets associated to specific geographical locations. Whenever energy or materials were required for a technological process, we applied the market datasets associated with the specific geographical location (such as Europe) to the extent possible.

Table 6. Data completeness assessment. Inventory of the available data at the beginning of the LCA study (without assumptions). "X" in the table represents available data.

Packaging material	End-of-life scenarios										
	RS, SC, INC	RS	RS	RS	SC	SC	SC	RS, SC	RS, SC, INC	RS, SC, INC	RS, SC, INC
	Physic-chemical composition	Collection and transport (DK)	Fine sorting (DK)	Recycling, high quality (EU)	Collection and transport (DK)	Coarse sorting (DK)	Fine sorting (EU)	Recycling, normal quality (EU)	Transport (EU)	Incineration residues (DK)	Incineration residues (EU)
Plastic, PET		X	X	X		X		X		X	X
Plastic, HDPE		X	X			X		X		X	X
Glass, clear	X	X	X	*		X		X*		X	X
Glass, green	X	X	X	*		X		X*		X	X
Glass, brown	X	X	X	*		X		X*		X	X
Aluminium	X	X	X			X		X		X	X
Composite, Tetra Pak	X	X	X			X		X		X	X

* Occurs in Denmark

3.10 Assumptions

First of all, the present LCA study included in the assessment the main beverage packaging material types that can potentially be included in the return system scheme. Additionally, the study considered disposal of composite packaging materials. Other types of beverage packaging materials were excluded from the assessment. The functional unit and the reference flow assess one material at a time, and assume that the recycled material competes only with virgin or recycled material of the same type.

In order to provide for the missing data identified in the completeness assessment (Table 6), assumptions had to be made. The assumptions are reported in the following list and Table 7, subdivided according to the main data requirement topic:

- **Physico-chemical composition data**
  For PET and HDPE, the same physico-chemical composition of waste plastic bottles was assumed. Moreover, we assumed that the collected beverage packaging waste contained a limited amount of impurity (0.1 % by weight). The impurity was assumed as dirty paper, for example the labels on the bottles or cans, plastic (lids), or other waste that could be inside the beverage container, such as kitchen towels, dirty paper, and ashes.

  The impurity was considered the same for all materials and scenarios. The purity (99.9%) was considered the same between RS, SC and INC since the reference flow is the beverage packaging material only. The lower expected purity in the SC system was reflected on the lower efficiencies of the sorting phases.

- **Collection and transport**
  In order to supply for missing collection and transport data, average distances were assumed in accordance with the project partners. Detailed data on transport distances is provided in Appendix A.

- **Sorting**
  We assumed that COWI data for fine sorting in Denmark (material and energy requirements and sorting efficiency) (COWI, 2017) could be valid for fine sorting in Europe as well. The efficiency of fine sorting abroad from the source segregated stream (85%) was assumed to be lower than the efficiency of fine sorting of the return system in Denmark.

- **Recycling**
  In order to supply for the missing data on high quality recycling to food grade products, we modified the "normal quality" recycling processes for each material type by increasing the recycling efficiency. A detailed summary of these assumptions is provided in Detail in Section 4 and in Appendix A.

- **Treatment of residues**
  We assumed that the end-of-life of residues from recycling abroad is sent to incineration. Incineration in Denmark was modelled taking into account direct emissions based on the physico-chemical composition of the material, while incineration abroad was modelled with a generic incineration process. When available, incineration for the specific material types was selected. For the composite beverage packaging material, a specific incineration process was not available and incineration for municipal solid waste was selected instead.

- **Material and energy requirements**
  If European "market" datasets (representing the European market mix in Ecoinvent) were not available, production data or data with lower geographical representativeness were used instead. For the specific case of recovered materials from the recycling process, we modelled the avoided production of primary materials using production data for Europe. For food-grade material recycling, only data regarding food grade PET was available. For the remaining materials, high quality recycling was modelled increasing the recycling efficiency.

- **Capacities for waste management technologies**
  In the modelling we assumed that sufficient capacity existed for all waste management technologies in all scenarios. As such, waste flows and waste management outside the included scenarios and in other countries were assumed not to be affected by the assessed scenarios. Dansk Retursystem A/S is currently in the process of expanding their current capacity, it is expected that capacity for the additional packaging is not a problem for Dansk Retursystem A/S; this constraint has therefore not been included in the modelling. The potential change in waste material flows to waste incineration represents less than 0.1% of the amount being treated (Miljøstyrelsen, 2017; Miljøstyrelsen, 2018; The Nielsen Company, 2018). As such, the potential effects on waste flows represented by this project are considered marginal with respect to installation/decommissioning of capacities.

Table 7. Data assumptions with respect to the beverage packaging waste material and location in the modelling. “X” indicates where data was already present and did not require assumptions.

	End-of-life scenarios										
	RS, SC, INC	RS	RS	RS	SC	SC	SC	RS, SC	RS, SC, INC	RS, SC, INC	RS, SC, INC
Packaging material	Physic-chemical com-position	Collection and transport (DK)	Fine sorting (DK)	Recycling, high quality (EU)	Collection and transport (DK)	Coarse sorting (DK)	Fine sorting (EU)	Recycling, normal quality (EU)	Transport (EU)	Incineration residues (DK)	Incineration residues (EU)
Plastic, PET	X	X	X	X		X		X		X	X
Plastic, HDPE	X	X	X	Assumed, increased recycling efficiency of normal recycling		X		X		X	X
Glass, clear	X	X	X			X		X*		X	X
Glass, green	X	X	X	Assumed, increased recycling efficiency of normal recycling *	Assumed average distance	X	Assumed from DK data, SC	X*	Assumed average distance	X	X
Glass, brown	X	X	X			X		X*		X	X
Aluminium	X	X	X	Assumed, increased recycling efficiency of normal recycling		X		X		X	X
Composite, Tetra Pak	X	X	X			X		X		X	X

* Occurs in Denmark

3.11 Data quality assessment

The beverage packaging material types included in the assessment are considered sufficiently representative of the beverage packaging products currently available on the market in Denmark. The materials included in the assessment (PET, HDPE, glass and aluminium) are currently already collected by the return system.

Considering the same material composition for PET and HDPE means that in EASETECH the physico-chemical properties associated to such materials are the same. These are for example energy content, fossil carbon content, etc. In the modelling, this mainly influences the potential energy recovery in the waste to energy as well as emissions contributing to climate change and toxicity impacts. The plastic polymers are quite similar, and this is therefore found of minor importance. The assumption regarding the small impurities that can be present within the collected beverage packaging waste is considered realistic and conservative. This assumption considers that the small unwanted waste might be present within the collected beverage packaging, for example paper tissues, ashes, cigarette butts. The presence of unwanted material slightly lowers the purity of the collected material (as explained in 3.8), which corresponds to the relative amount of recyclable beverage material among the overall collected material.

The assumed transportation distances, which were the same for all the assessed beverage packaging waste types, reflect that transportation could occur partly within Denmark and partly in other European countries. The chosen transportation distances were considered realistic and were agreed with the project partners.

Regarding the datasets retrieved from the Ecoinvent database, the consequential version of the database is considered consistent with the goal and scope of this LCA study. The version of the database employed for this LCA was the latest available (3.4). All datasets used for this study have been tested for their environmental impacts against other datasets for similar materials and energy before being selected and implemented in the modelling to ensure that they perform similar to comparable processes.

The data utilized to model material and energy requirements in the waste management and recycling processes were retrieved from a series of well-documented studies in the literature, as reported in detail in Appendix A.

Sorting efficiencies assumed for Denmark are considered reliable. They are based on a recent COWI (2017) project which gathered the data as a generic process based on a number of existing facilities. Furthermore the assumption for fine sorting efficiencies in Europe having a still lower than Return System sorting efficiencies is considered reliable as the source of the sorting is here based on more mixed materials.

The assumption on modelling the recovered material as avoided production data for Europe is considered conservative: the use of market datasets or datasets with lower geographical representativeness would provide slightly higher savings. Specific datasets were available for all the materials assessed in this LCA for the “normal quality” recycling, while data for food-grade material was available only for PET. The production of food-grade PET provides higher environmental impacts than the production of normal PET; therefore, using food-grade PET datasets for modelling recycling (avoided production) provides higher savings than using normal PET datasets.

For this reason, for the remaining materials without an available food-grade dataset, modelling food-grade recycling was carried out by increasing the recycling rate, which eventually provides higher savings.

Data for end-of-life is considered technologically reliable. EASETECH allows modelling waste management as input-specific, which means that they changed based on changes in the physico-chemical input to the processes. Values characterizing the incineration process are based on peer-reviewed literature and are extensively reported in Appendix A.

3.11.1 Critical assumptions

Overall, the present LCA study involves a series of assumptions. The following assumptions were considered critical for the outcomes of the study:

- Even if the functional unit is based on beverage packaging products not yet included in the return system in 2017, the study is assumed to support decisions that may occur in a 10 years period. Using a future marginal energy is assumed to appropriately represent the effects in the future waste management system. Using a non-future marginal energy would have entailed having coal in the energy mix, and would have provided higher savings from energy recovery in the incineration process. The inclusion of a minor percentage of coal in the marginal heat process means that waste to energy comes out a little better, than if it was

fully phased out. Coal is most likely not a marginal in the full 10 year period, and in the latter phase this would lead to higher impacts from waste to energy, meaning that the two recycling options would come out even better. A system completely based on renewable sources is also a possibility in the long term. However, it is considered unlikely that such a system is implemented within the time horizon for the present assessment, but such a change would make recycling even better than incineration. A sensitivity assessment was carried out on the marginal energy and results included in Appendix C.
- Assumption on higher recycling rates (fewer residues in recycling) in high quality recycling for materials without food-grade dataset are important as this entails higher avoided impacts. It is found realistic as quality control for this type of production is higher and therefore will imply a larger use of material and energy in production, which is taken into account by the higher recycling rate.
- The inclusion of construction and decommissioning of capacities could be important as impacts from infrastructure may have high impacts in some impact categories. The return system is in the process of being expanded. Including the environmental impacts from construction of the additional capacity will add additional impacts to the return system, while potential spare incineration capacity may induce additional savings. However, assumptions related to potential changes in capacity and cause-effect relationships may be close to speculation and at least very uncertain. Considering the marginal changes in the associated waste flows, we find the omission of impacts from construction/decommissioning justifiable
- Sorting efficiencies are very important as they directly affect the avoided production. As they are linearly linked to the final avoided amount they are important to have with a high precision. In this study the return system values are based directly on facility data, whereas the data for the normal recycling system is based on literature values. The assumed values for the return system are therefore considered to be reliable.

3.12 Cut-offs

As presented in the scope section, the assessment did not include construction and decommissioning of infrastructure, buildings, machinery (capital goods), or analyses of existing capacities and new capacities requirements. First of all, capacity for the return system and separate collection scheme is planned to be increased. Nevertheless, another reason for not including capacity was to distinguish capacity issues from the environmental performance of the beverage packaging and let the stakeholders decide on whether it was worth assessing and adding new capacity, and for which material types. Increasing capacity of both systems will require material resources and energy, which will increase the environmental impact associated with both systems.

3.13 Limitations

It is believed that the data used and the assumptions taken as described above will not result in significant limitations to the interpretation of the results.

3.14 Life Cycle Interpretation

Section 6 provides the results of the LCA for each beverage packaging material type. The results are provided as characterized impact scores for each of the impact categories listed in Section 3.6. Results are also provided as normalized impact scores following the normalization references listed in Appendix B. The normalization allows expressing the magnitude of the results relative to reference information and communicating the relative significance of the indicator results. The interpretation of the mono materials is found to be realistic as it considered what would happen if materials were sent to the specific treatment, and are here linked to real data.

Section 7 includes a discussion on which disposal option among the ones assessed comes out as preferred on basis of the results in Section 6 (Section 7.1). Section 7.2 provides a discussion on the influence on data quality and assumptions on the results obtained. Furthermore, section 7 includes two additional subchapters to further improve the understanding of the role of the different beverage packaging materials. The first subchapter (7.3) provides the impacts associated with the production of each beverage packaging material type. The results are provided as characterized impact scores for each of the impact categories listed in Section 3.6. These results are included to contextualize the magnitude of the results for the waste management phase (presented in section 6 and discussed in 7.1 and 7.2) with the impacts associated to the production of the material. The impacts associated to the production of each material do not include the manufacturing of the beverage packaging product, and should therefore only be used to contextualize the environmental impacts of the management of the waste beverage packaging materials. To choose which materials to be used for beverage packaging a full LCA should be carried out.

The second subchapter (7.4) illustrates results of potential future scenarios for the management of beverage packaging waste. Currently, not all beverage packaging products are managed via the return system, but are partly collected via separate collection or incinerated with the residual waste. The systems illustrated in 7.4 investigate potential systems where the beverage types are included in the return system, and where beverage packaging products partly are composed by composite materials. The scenarios are based on current amounts. The results are presented as a mass balance. The mass balance was used to scale the results of the mono-material LCA to obtain potential and streamlined LCA results of the scenarios investigated. However this is not a fully consequential LCA on the future beverage packaging waste management system, as we only investigated current production rates, without considering what the future packaging materials would be. However, the aim of this part was to obtain a potential magnitude of the environmental impacts associated to the future systems investigated. The results are presented as normalized impact scores following the normalization references listed in Appendix B.

3.15 Critical review

This LCA study includes a critical review, carried out by Line Geest Jakobsen and Trine Lund Neidel from COWI A/S in May 2018. The aim of the critical review is to assess the compliance of the LCA study with the ISO standard and to increase the clarity and usefulness of the result.

Although this LCA might be used to support decisions and that the comparative assertion might ultimately be disclosed to the public, there are pre-defined limitations to the study regarding the fact that the critical review was not conducted while the project was being carried out and by a panel of interested parties. For this reason, the report does not fully comply with the ISO standard. The critical review is provided in Appendix E and the main outcomes are summarized in the Executive Summary.

3.16 Format of the report

The format of the report is:

- Short executive summary in Danish (7 pages);
- Short executive summary in English (6 pages);
- Technical LCA report.

4. Mono material scenarios

As explained in Section 3.7, the scenarios assessed in this LCA study were the result of a combination of each of the selected beverage packaging materials (PET, HDPE, clear glass, green glass, brown glass, aluminium and composite) with each of the considered end-of-life options: collection and recycling within the return system (RS), collection and recycling within the source segregated waste (SC), and incineration (INC). General details about the end-of-life scenarios were provided in Section 3.7.

This section provides the main modelling features adopted for the specific beverage packaging material types, as well as an overview of purity, sorting, recycling efficiency and total recovered materials. Details on the material and energy requirements of the waste management processes are provided in Appendix A. Details on the avoided material and energy production are provided in Appendix B.

4.1 PET

PET beverage packaging is collected with an assumed purity of 99.9 %. Possible impurities were considered as dirty paper (labels), plastic (lids), or other waste that could be inside the beverage container, such as kitchen towels, dirty paper, and ashes.

When PET is collected by the return system, the material is separated in a sorting facility in Denmark to 97.7 % high quality PET and 2.2 % normal quality PET. The last 0.1 % of material is rejected and incinerated in Denmark (Dansk Retursystem A/S, 2017). The high quality and normal quality material is shipped for recycling in Europe. When PET is collected within the separate collection scheme, it undergoes first a coarse sorting in Denmark, and secondly a fine sorting in Europe. Both sorting processes have a sorting efficiency of 85 % (COWI, 2017), for a total sorting efficiency of 72 %. In the case of the incineration scenario, 100 % of the material is collected within the residual waste fraction and incinerated.

For modelling of PET Recycling in Europe of high quality recycling (food grade) the technological efficiency (A factor, Eq. 1, Section 3.8) was set to 98 % according to Aage Vestergaard Larsen A/S (2018), while the market response (B factor, Eq. 2) was set to 100 %. In the case of high quality recycling, the amount of recovered material was modelled by avoiding the production of PET granulate, bottle grade, amorphous, in Europe. For modelling of PET recycling of normal quality (non-food grade), it was modelled according to the studies of Giugliano et al. (2011), Perugini et al. (2005), and Rigamonti et al. (2014). The A factor was set to 75.5 %, and the B factor was set to 81 %. The resulting amount of material recovered was modelled by avoiding the production of the same amount of primary material, which was PET granulate, amorphous, in Europe.
The rejects from sorting in Denmark and the residual waste stream from the incineration end-of-life scenario (INC) are incinerated in Denmark, while residues generated in Europe from the recycling process are incinerated abroad.

4.2 HDPE

HDPE beverage packaging is collected with an assumed purity of 99.9 %. Possible impurities were considered as dirty paper (labels), plastic (lids), or other waste that could be inside the beverage container, such as kitchen towels, dirty paper, and ashes.

When HDPE is collected by the return system, the material is separated in a sorting facility in Denmark to 97.7 % high quality HDPE and 2.2 % normal quality HDPE. 0.1 % of material is rejected and incinerated in Denmark (Dansk Retursystem A/S, 2017). The high quality and normal quality material is shipped for recycling in Europe. When HDPE is collected within the separate collection scheme, it undergoes first a coarse sorting in Denmark, and secondly a fine sorting in Europe. Both sorting processes have a sorting efficiency of 85 % (COWI, 2017), for a total sorting efficiency of 72 %. In the case of the incineration scenario, 100 % of the material is collected within the residual waste fraction and incinerated.

HDPE recycling in Europe (normal quality) was modelled according to the studies of Giugliano et al. (2011), Perugini et al. (2005), and Rigamonti et al. (2014). The technological efficiency (A factor, Eq. 1, Section 3.8) was set to 90 %, and the market response (B factor, Eq. 2) was set to 81 %. The resulting amount of material recovered was modelled by avoiding the production of the same amount of primary material, which was HDPE granulate, amorphous, in Europe. For modelling high quality recycling (food grade), a food-grade primary production dataset (as in the case of PET) was not available. High quality recycling was then modelled by increasing B, which was set to 100 %.

The rejects from sorting in Denmark and the residual waste stream from the incineration end-of-life scenario (INC) are incinerated in Denmark, while residues generated in Europe from the recycling process are incinerated abroad.

4.3 Clear glass, green glass, brown glass

Clear glass, green glass and brown glass were modelled as three different scenarios due to their different material composition and the different materials recovered. The remaining features are common between the scenarios, which are summarized below.

Glass beverage packaging is collected with an assumed purity of 99.9 %. Possible impurities were considered as dirty paper (labels), plastic (lids), or other waste that could be inside the beverage container, such as kitchen towels, dirty paper, and ashes.

When glass is collected by the return system, the material is separated in a sorting facility in Denmark to 97.7 % high quality glass and 2.2 % normal quality glass. 0.1 % of material is rejected and incinerated in Denmark (Dansk Retursystem A/S, 2017). The high quality and normal quality material is shipped for recycling in Denmark. When glass is collected within the separate collection scheme, it undergoes a coarse sorting and a fine sorting in Denmark. Both sorting processes have a sorting efficiency of 85 % (COWI, 2017), for a total sorting efficiency of 72 %. Currently material collected for recycling is screened for reuseable bottles, this is not included in the modelling due to uncertainty on the fate of the bottles, but this will make the effect of recycling from municipal collectiong slightly better. In the case of the incineration scenario, 100 % of the material is collected within the residual waste fraction and incinerated.

Glass recycling was modelled according to Glass Technology Services British. A was reported to be 94 % when a pre-treatment was required, 100 % otherwise. B was set to be 100 % as we assumed there was no difference between primary and virgin glass. For modelling high quality recycling (food grade), a food-grade primary production dataset (as in the case of PET) was not available. Normal quality recycling was modelled with A set to 94 %, high quality recycling was modelled with A set to 100 %. The resulting amount of material recovered was modelled by avoiding the production of the same amount of primary material, which was packaging glass production in Europe, clear, green or brown depending on the specific scenario.

The rejects from sorting and recycling were incinerated in Denmark, as well as the residual waste stream from the incineration end-of-life scenario (INC).

4.4 Aluminium

Aluminium beverage packaging is collected with an assumed purity of 99.9 %. Possible impurities were considered as dirty paper (labels), plastic (lids), or other waste that could be inside the beverage container, such as kitchen towels, dirty paper, and ashes.

When aluminium is collected by the return system, the material is separated in a sorting facility in Denmark to 97.7 % high quality aluminium and 2.2 % normal quality aluminium. 0.1 % of material is rejected and incinerated in Denmark (Dansk Retursystem A/S, 2017). The high quality and normal quality material is shipped for recycling in Europe. When aluminium is collected within the separate collection scheme, it undergoes first a coarse sorting in Denmark, and a second fine sorting in Europe. Both sorting processes have a sorting efficiency of 85 % (COWI, 2017), for a total sorting efficiency of 72 %. In the case of the incineration scenario, 100 % of the material is collected within the residual waste fraction and incinerated.

Aluminium recycling in Europe (normal quality) was modelled according to the study of Rigamonti et al. (2009). A was set to 93 %; B was set to 100 %. Since a food-grade primary material production dataset was not available, high quality recycling was modelled by setting A equal to 100 %. The resulting amount of material recovered was modelled by avoiding the production of the same amount of primary material, which was primary aluminium ingot production, in Europe.

The rejects from sorting in Denmark and the residual waste stream from the incineration end-of-life scenario (INC) are incinerated in Denmark, while residues generated in Europe from the recycling process are incinerated abroad.

4.5 Composite

The composite material scenario models carton containers with composed of carton, PE and aluminium foil. The distribution between carton (75 %), PE (20 %) and aluminium (5 %) was based on the studies from Banar et al. (2008), Pasqualino et al. (2011), and Yan et al. (2015).

Juice and milk carton containers are not currently part of the return system, nor are separately collected with paper or cardboard. We still decided to include them for all three disposal options for completeness. We assumed the same sorting efficiencies of the other packaging materials, which were 97.7 % to high quality recycling and 2.2 % to normal quality recycling for the return system, and overall 72 % for the separate collection. However, implementation of such scheme would require verifying that composites can be sampled with the same equipment and the same efficiency as the other materials.

The recycling process (normal quality) was based on the study from Pasqualino et al. (2011). Cardboard is recycled with a technological efficiency (A) of 93 % and a market response (B) of 100 %. PE plastic foil and aluminium foil are separated but discarded. Recovery of material was modelled by avoiding the production of linerboard. High quality recycling was modelled by increasing A to 100 %.

The rejects from sorting in Denmark and the residual waste stream from the incineration end-of-life scenario (INC) are incinerated in Denmark, while residues generated in Europe from the recycling process are incinerated abroad.

4.6 Overview

This section provides an overview of the data on purity, sorting and recycling efficiencies of the beverage packaging waste scenarios presented above. Table 8 provides details about high quality recycling via the return system, Table 9 provides details on normal quality recycling of materials separated by the return system, and Table 10 provides details about the separate collection scenarios. By comparing values between Table 8 and Table 10 can be seen the difference in recovered material that will displace new material.

Table 8. Purity, sorting efficiency, technological efficiency (A), market response (B), total recycling efficiency and recovered material for each of the beverage packaging materials for the RS end-of-life scenario, high quality recycling.

Packaging material	Purity (%)	Sorting, high quality (DK) (%)	A (%)	B (%)	Total Recycling Efficiency (%)	Total Recovered material (%)
PET	99.9	97.7	98.0	100	98.0	95.7
HDPE	99.9	97.7	90.0	100	90.0	87.9
Glass, clear	99.9	97.7	100.0	100	100.0	97.7
Glass, green	99.9	97.7	100.0	100	100.0	97.7
Glass, brown	99.9	97.7	100.0	100	100.0	97.7
Aluminium	99.9	97.7	100.0	100	100.0	97.7
Composite	75.0*	97.7	100.0*	100	100.0*	97.7

* Only the cardboard part

Table 9. Purity, sorting efficiency, technological efficiency (A), market response (B), total recycling efficiency and recovered material for each of the beverage packaging materials for the RS end-of-life scenario, normal quality recycling.

Packaging material	Purity (%)	Sorting, normal quality (DK) (%)	A (%)	B (%)	Total recycling efficiency (%)	Total recovered material (%)
PET	99.9	2.2	75.5	81.0	61.2	1.3
HDPE	99.9	2.2	90.0	81.0	72.9	1.6
Glass, clear	99.9	2.2	94.0	100	94.0	2.1
Glass, green	99.9	2.2	94.0	100	94.0	2.1
Glass, brown	99.9	2.2	94.0	100	94.0	2.1
Aluminium	99.9	2.2	93.0	100	93.0	2.0
Composite	75.0*	2.2	93.0*	100	93.0	2.0

* Only the cardboard part

Table 10. Purity, sorting efficiency, technological efficiency (A), market response (B), total recycling efficiency and recovered material for each of the beverage packaging materials for the SC end-of-life scenario.

Packaging material	Purity (%)	Coarse sorting (DK) (%)	Fine Sorting (EU) (%)	A (%)	B (%)	Total Recycling Efficiency (%)	Total Recovered material (%)
PET	99.9	85.0	85.0	75.5	81.0	61.2	44.2
HDPE	99.9	85.0	85.0	90.0	81.0	72.9	52.7
Glass, clear	99.9	85.0	85.0	94.0	100	94.0	67.9
Glass, green	99.9	85.0	85.0	94.0	100	94.0	67.9
Glass, brown	99.9	85.0	85.0	94.0	100	94.0	67.9
Aluminium	99.9	85.0	85.0	93.0	100	93.0	67.2
Composite	75.0*	85.0	85.0	93.0*	100	93.0	67.2

* Only the cardboard part

5. Mass balance: recycled material

The present section provides the mass balance of the recovered material for each beverage packaging waste for the return system (RS) and separate collection (SC) end-of-life scenarios.

Table 11 provides the amounts of recycled material of high and normal quality recovered by the return system, as well as the amount of waste generated. Glass and aluminium provided the highest amounts of recycled material of high quality. Composite provided the lowest amount due to the fact that the recoverable material in the beverage packaging, which is cardboard, is only a fraction of the beverage packaging material (75 %). HDPE provided a lower amount of high quality recycled material than PET. Glass and aluminium also provided the highest amounts of recycled material of normal quality, and the lowest overall amount of generated waste.

Table 12 provides the amounts of recovered material and waste generated by the separate collection scenarios. For the source segregation scenarios, recycling did not provide high quality food-grade materials. Therefore, the amount of recycled material of normal quality equals the amount of recycled material in total.

Also for the separate collection scenarios, glass and aluminium provided the highest amount of total material recycled (due to the high technological efficiency and market response). PET provided lower material recovery than HDPE and the composite material.

Table 11. Amount of recycled material of high and normal quality and generated waste via the return system (RS) end-of-life scenario. Amounts are given per ton of collected material (reference flow), before losses in recycling processes.

Beverage packaging material	Recycled material, high quality (kg)	Recycled material, normal quality (kg)	Total recycled material (kg)	Residues (kg)
PET	956.9	13.4	970.3	29.7
HDPE	878.8	16.0	894.8	105.2
Glass, clear	976.4	20.7	997.1	2.9
Glass, green	976.4	20.7	997.1	2.9
Glass, brown	976.4	20.7	997.1	2.9
Aluminium	976.4	20.4	996.9	3.1
Composite	732.3	15.3	747.6	252.4

Table 12. Amount of recycled material and generated waste via the separate collection (SC) end-of-life scenario. No high quality material as recyclables are collected mixed with non-food grade materials. Amounts are given per ton of collected material (reference flow) before losses in recycling processes.

Beverage packaging material	Recycled material, high quality (kg)	Recycled material, normal quality (kg)	Total recycled material (kg)	Residues (kg)
PET	-	441.6	441.6	558.4
HDPE	-	526.4	526.4	473.6
Glass, clear	-	678.7	678.7	321.3
Glass, green	-	678.7	678.7	321.3
Glass, brown	-	678.7	678.7	321.3
Aluminium	-	671.5	671.5	328.5
Composite	-	503.6	503.6	496.4

Figure 2 illustrates the amounts of recycled material of high quality and normal quality, as well as amounts of generated waste, for each beverage packaging material type and the return system and separate collection scenarios. Only the RS recover material for replacing food grade quality (High quality), whereas the SC system only recover material for non-food grade products (normal quality). PET, glass, and aluminium were the materials with the highest recovery via the return system, and where a large majority is recovered for high quality recycling. The recovery efficiency of the return system was always higher than the recovery efficiency of the separate collection for the same beverage packaging waste material. PET, HDPE and composite were the beverage packaging materials types with the lowest recycled material when collected via separate collection.

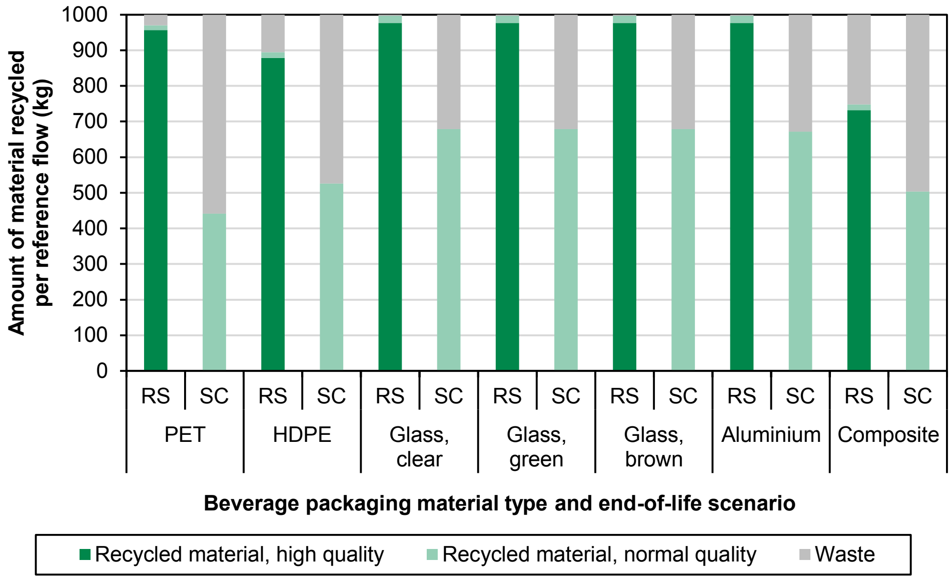


Figure 2. Amounts of material recycled with high quality and normal quality, as well as amounts of generated waste, for each beverage packaging material type and the return system and separate collection scenarios.

6. Life Cycle Impact Assessment

This section provides the results of the Life Cycle Impact Assessment. Characterized result scores are provided in the following Tables 13 – 15. Normalized result scores are provided in Tables 16 – 18 in persons equivalents (PE).
The magnitude of the result scores showed high dependence on the beverage packaging material type. For example, aluminium provided the absolute highest savings when recycled, due to the avoided production of aluminium material, which was characterized by the highest environmental impacts among the assessed materials.

For this reason, we provided in the following sections a dedicated description of the results focusing on the beverage packaging material type. We also focused on the contribution to the results of the phases of the waste management system as shown in Figure 1: collection and transport, recycling, incineration of residual waste and of the residues from recycling. This was combined with figures showing the contribution of different processes to the climate change impact category

The normalized results provide additional information on the relative significance of the indicator results compared to each other. They are only discussed in general as the details are discussed in the contribution analysis.

The magnitude of the results obtained and described in this section was compared with the environmental impacts associated to the production of the associated beverage packaging material in Section 7.

Table 13. Characterized results for the RS end-of-life scenario, for each of the waste beverage packaging material and impact categories assessed. Results are expressed as characterized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	kg CO_2 eq	kg CFC11 eq	CTUh	CTUh	kgPM2.5 eq	kBq U235 eq	kg NMVOC	mol H+ eq	mol N eq	kg P eq	kg N eq	CTUe	MJ	kg Sb eq
PET	-2.7E+03	-6.6E-05	-4.9E-05	-2.9E-04	-2.0E+00	-2.2E+01	-7.9E+00	-1.1E+01	-2.1E+01	-2.8E-01	-1.9E+00	-1.7E+03	-7.5E+04	-1.7E-01
HDPE	-1.4E+03	3.7E-05	-1.3E-05	-2.4E-05	-8.1E-01	1.6E+01	-7.7E+00	-7.5E+00	-1.3E+01	-1.5E-02	-1.2E+00	-3.5E+02	-6.2E+04	2.5E-03
Glass, clear	-4.0E+02	-3.3E-05	-9.9E-06	-5.5E-05	-8.6E-01	-9.6E+00	-4.9E-01	-1.8E+00	-5.9E+00	-7.2E-02	-1.7E-01	-3.8E+02	-4.9E+03	-5.7E-02
Glass, green	-4.5E+02	-3.9E-05	-1.0E-05	-6.3E-05	-9.0E-01	-1.1E+01	-6.7E-01	-2.1E+00	-6.8E+00	-7.7E-02	-2.2E-01	-4.4E+02	-5.9E+03	-5.9E-02
Glass, brown	-3.9E+02	-3.2E-05	-9.8E-06	-5.4E-05	-8.5E-01	-9.1E+00	-4.6E-01	-1.8E+00	-5.9E+00	-7.2E-02	-1.6E-01	-3.7E+02	-4.8E+03	-5.7E-02
Aluminium	-8.5E+03	-7.7E-04	-8.3E-04	-1.9E-03	-5.6E+00	-7.1E+02	-2.5E+01	-5.3E+01	-6.4E+01	-5.0E-01	-5.3E+00	-1.1E+04	-1.3E+05	-7.3E-02
Composite	-3.5E+02	-6.4E-05	-3.0E-06	-1.5E-04	4.7E-01	-1.9E+01	-1.1E+00	-9.7E-01	-9.6E-01	-3.9E-02	-3.5E-01	-2.9E+01	-4.5E+03	-2.3E-01

Table 14. Characterized results for the SC end-of-life scenario, for each of the waste beverage packaging material and impact categories assessed. Results are expressed as characterized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	kg CO_2 eq	kg CFC11 eq	CTUh	CTUh	kgPM2.5 eq	kBq U235 eq	kg NMVOC	mol H+ eq	mol N eq	kg P eq	kg N eq	CTUe	MJ	kg Sb eq
PET	-5.9E+02	-3.3E-05	-2.2E-05	-2.3E-04	-1.1E+00	-1.3E+01	-4.3E+00	-7.9E+00	-1.4E+01	-1.5E-01	-1.1E+00	2.8E+03	-4.1E+04	-6.0E-02
HDPE	-4.6E+02	7.2E-06	-1.1E-05	-1.5E-04	-7.6E-01	5.3E+00	-5.6E+00	-7.7E+00	-1.3E+01	-5.8E-02	-1.0E+00	1.5E+02	-4.5E+04	-1.9E-04
Glass, clear	-1.9E+02	-1.7E-05	-6.1E-06	-2.4E-05	-4.9E-01	-5.2E+00	1.7E-01	-5.7E-01	-2.2E+00	-4.6E-02	4.7E-02	-1.7E+02	-2.4E+03	-3.8E-02
Glass, green	-2.3E+02	-2.1E-05	-6.3E-06	-3.0E-05	-5.3E-01	-6.2E+00	4.7E-02	-7.9E-01	-2.8E+00	-5.0E-02	8.0E-03	-2.1E+02	-3.1E+03	-3.9E-02
Glass, brown	-1.9E+02	-1.6E-05	-6.1E-06	-2.4E-05	-4.9E-01	-4.9E+00	1.9E-01	-5.7E-01	-2.2E+00	-4.6E-02	5.1E-02	-1.7E+02	-2.3E+03	-3.8E-02
Aluminium	-7.0E+03	-5.7E-04	-6.5E-04	-1.3E-03	-5.0E+00	-5.1E+02	-2.1E+01	-4.3E+01	-5.3E+01	-3.8E-01	-4.4E+00	-8.7E+03	-1.0E+05	7.8E-01
Composite	-1.9E+02	-5.8E-05	-3.2E-06	-1.5E-04	2.3E-01	-1.7E+01	-1.0E+00	-1.4E+00	-1.7E+00	-3.6E-02	-3.0E-01	2.0E+02	-5.2E+03	-3.1E-01

Table 15. Characterized results for the INC end-of-life scenario, for each of the waste beverage packaging material and impact categories assessed. Results are expressed as characterized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	kg CO_2 eq	kg CFC11 eq	CTUh	CTUh	kgPM2.5 eq	kBq U235 eq	kg NMVOC	mol H+ eq	mol N eq	kg P eq	kg N eq	CTUe	MJ	kg Sb eq
PET	9.1E+02	-1.4E-04	-1.1E-05	-5.5E-04	-1.3E+00	-2.1E+01	-4.7E+00	-9.9E+00	-2.2E+01	-7.1E-02	-1.4E+00	-7.1E+02	-2.5E+04	-1.5E-02
HDPE	9.1E+02	-1.4E-04	-1.1E-05	-5.5E-04	-1.3E+00	-2.1E+01	-4.7E+00	-9.9E+00	-2.2E+01	-7.1E-02	-1.4E+00	-7.1E+02	-2.5E+04	-1.5E-02
Glass, clear	6.6E+01	8.8E-06	2.7E-07	1.0E-05	6.4E-02	2.5E+00	1.1E+00	9.4E-01	4.4E+00	1.8E-03	4.0E-01	7.0E+01	1.1E+03	-2.7E-03
Glass, green	5.7E+01	8.3E-06	1.1E-06	7.1E-06	5.6E-02	2.5E+00	1.1E+00	8.8E-01	4.3E+00	1.4E-03	3.9E-01	8.0E+01	9.4E+02	-3.1E-03
Glass, brown	5.9E+01	8.4E-06	3.4E-07	7.7E-06	5.8E-02	2.5E+00	1.1E+00	8.9E-01	4.3E+00	1.5E-03	3.9E-01	7.2E+01	9.6E+02	-3.0E-03
Aluminium	-2.8E+03	-2.3E-04	-2.5E-04	5.0E-04	-1.9E+00	-1.8E+02	-6.4E+00	-1.1E+01	-1.1E+01	-1.4E-01	-8.4E-01	-3.3E+03	-3.9E+04	-4.6E-02
Composite	-3.2E+02	-7.2E-05	-1.5E-05	-2.8E-04	-6.5E-01	-1.8E+01	-2.0E+00	-4.9E+00	-9.0E+00	-3.9E-02	-5.4E-01	-4.6E+02	-1.3E+04	-8.1E-03

6.1 PET

Result scores for the PET beverage packaging material for the climate change (CC) impact category are provided in Figure 3. For this impact category, PET beverage packaging material provided the highest net savings when collected and recycled via the return system (RS). The savings are due to the avoided production of food-grade PET obtained from the recycled high quality PET material. PET was the only beverage packaging material where high quality recycling could be modelled by avoiding food-grade material production. Lower savings were obtained by the separate collection management system (SC), due to the lower amount and quality of the material recycled and due to the impacts related to the incineration of residual waste and residues from recycling. Incineration of PET material (INC) provided net impacts, mainly due to the release to atmosphere of fossil carbon contained in the plastic. Collection and transport had a low contribution to the net results in all end-of-life scenarios. In tables 13-15 can be seen that RS provided a better performance than SC, with INC providing the highest impacts also for the impact categories human toxicity, cancer effects (HTC), freshwater eutrophication (FE), resource depletion fossil (RDfos) and abiotic (RD).

SC provided a worse performance than incineration for the following impact categories: particulate matter (PM), ionizing radiation (IR), photochemical ozone formation (POF), terrestrial acidification (TA), marine eutrophication (ME) and ecosystem toxicity (ET). INC provided higher savings in these categories due to the energy recovered during the process. RS still provided the best end-of-life option for these impact categories.

INC provided the highest savings for ozone depletion (OD), human toxicity, non-cancer effects (HTNC) and terrestrial eutrophication (TE) due to the savings from energy recovery. For these impact categories, RS provided a better performance than SC. However, INC provided a similar performance with respect to RS (within ±10 % of the RS result) for IR, TA and TE.

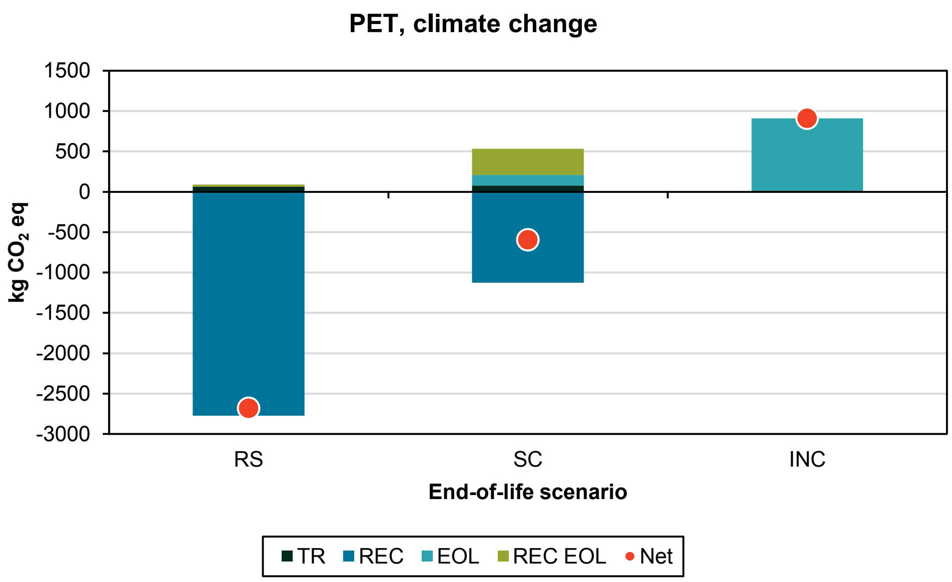


Figure 3. Characterized result scores for the PET beverage packaging material for the climate change impact category, expressed as kg CO_2 equivalents per reference flow. The results are provided for the three end-of-life options: return system (RS), separate collection (SC) and incineration (INC). The figure shows the contribution of the waste management phases to the final result. TR: collection and transport; REC: recycling; EOL: end-of-life, incineration of residual waste; REC EOL: incineration of residues from recycling.

6.2 HDPE

Results for the HDPE beverage packaging for CC are provided in Figure 4 and resemble the results obtained for the PET packaging material. The CC results showed the highest savings for RS, lower savings for SC and net impacts for INC. The difference in savings between RS and SC was less evident than in the case of PET, where recycling was modelled substituting the food-grade material production. Moreover, in comparison to PET, HDPE had lower amount of material sent to high quality recycling via the RS. INC provided net impacts due to the fossil carbon emitted during incineration. The same trend of CC could be observed for POF and RDfos. RS provided the lowest impacts also for the HTC impact category.

For the remaining impact categories (OD, HTNC, PM, IR, TA, TE, FE, ME, ET and RD), INC provided the lowest impacts, due to the energy recovered during the incineration process. In general, SC provided lower savings than RS due to the lower amount of recycled material and due to the management of the residues. SC provided a similar performance with respect to RS (within ±10 % of the RS result) for PM, TA and TE.

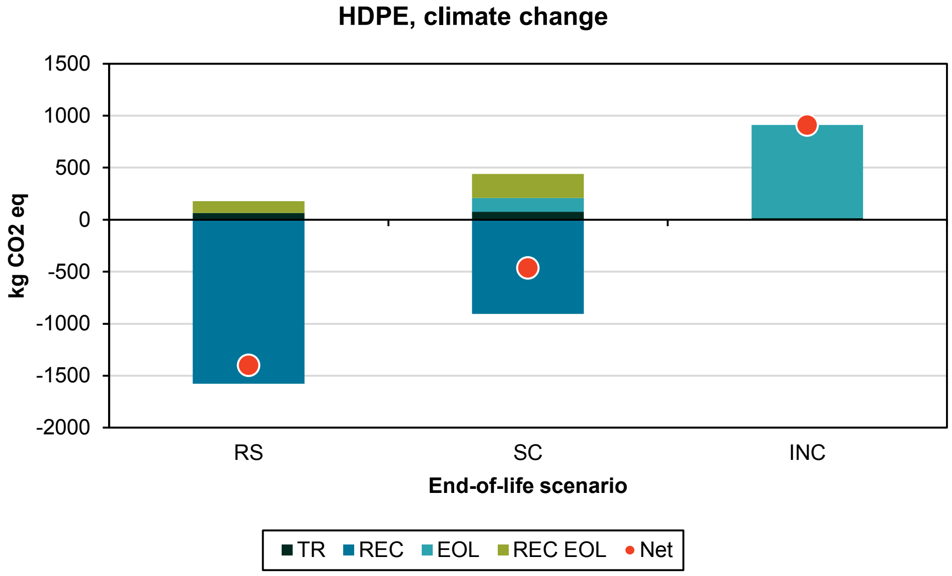


Figure 4. Characterized result scores for the HDPE beverage packaging material for the climate change impact category, expressed as kg CO_2 equivalents per reference flow. The results are provided for the three end-of-life options: return system (RS), separate collection (SC) and incineration (INC). The figure shows the contribution of the waste management phases to the final result. TR: collection and transport; REC: recycling; EOL: end-of-life, incineration of residual waste; RECEOL: incineration of residues from recycling.

6.3 Glass: clear, green and brown

The glass packaging materials assessed (clear glass, green glass and brown glass) provided the same results for the end-of-life options. The minor difference between the three glass types seen in Table 13-15 is due to small differences in the physico-chemical composition, which does not change the interpretation of glass across the three types. Figures 5 – 7 show the CC results for the three glass types assessed. Recycling via the RS provided the highest savings, due to the high amount of recycled material. Together with aluminium, glass presented the highest technological efficiencies and market responses, even for normal quality recycling. SC provided lower savings, due to the slightly lower amount of recovered glass and to the impacts related to the management of residual waste and waste from the recycling process. INC provided net impacts, since incineration of glass does not allow energy recovery and the only benefits from this waste management option were recovering of fly ash and bottom ash.

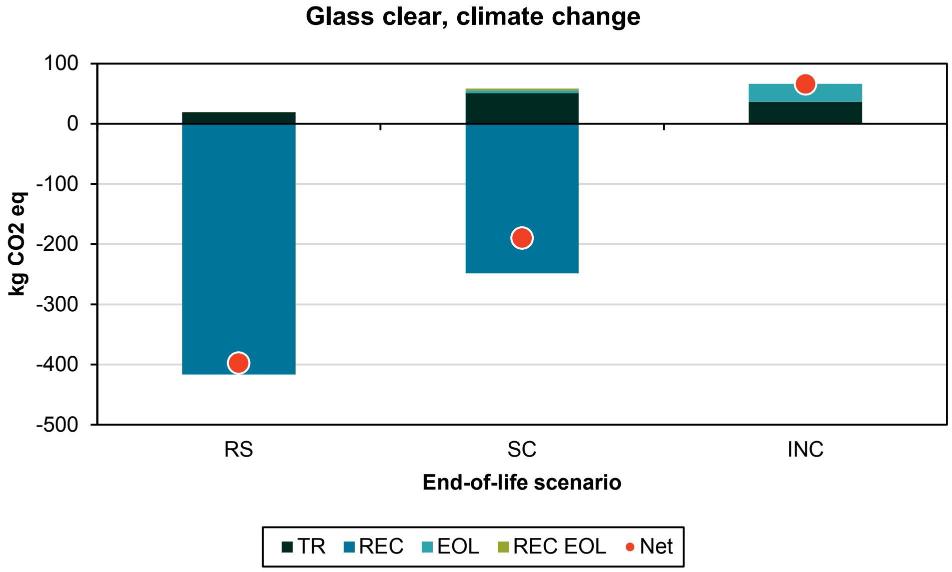


Figure 5. Characterized result scores for the clear glass beverage packaging material for the climate change impact category, expressed as kg CO_2 equivalents per reference flow. The results are provided for the three end-of-life options: return system (RS), separate collection (SC) and incineration (INC). The figure shows the contribution of the waste management phases to the final result. TR: collection and transport; REC: recycling; EOL: end-of-life, incineration of residual waste; RECEOL: incineration of residues from recycling.

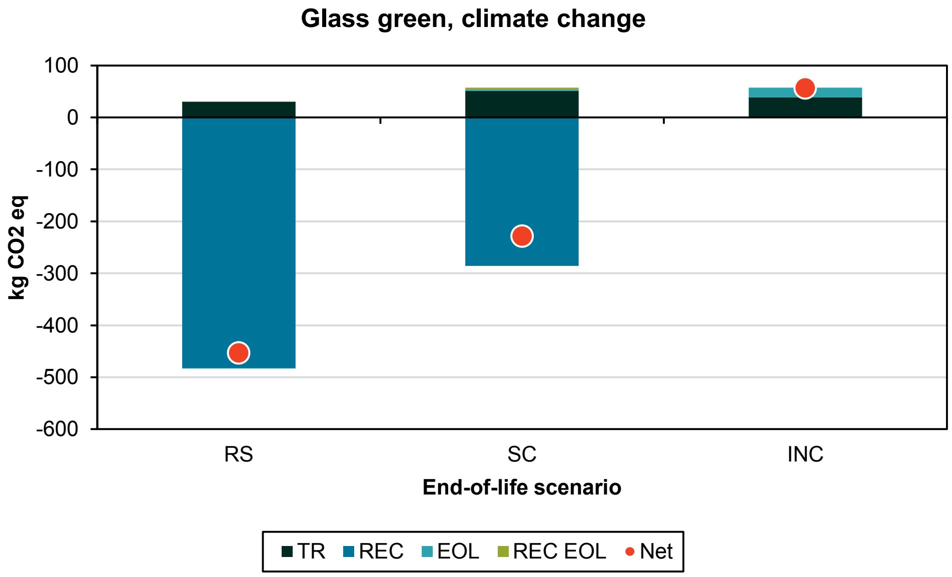


Figure 6. Characterized result scores for the green glass beverage packaging material for the climate change impact category, expressed as kg CO_2 equivalents per reference flow. The results are provided for the three end-of-life options: return system (RS), separate collection (SC) and incineration (INC). The figure shows the contribution of the waste management phases to the final result. TR: collection and transport; REC: recycling; EOL: end-of-life, incineration of residual waste; RECEOL: incineration of residues from recycling.

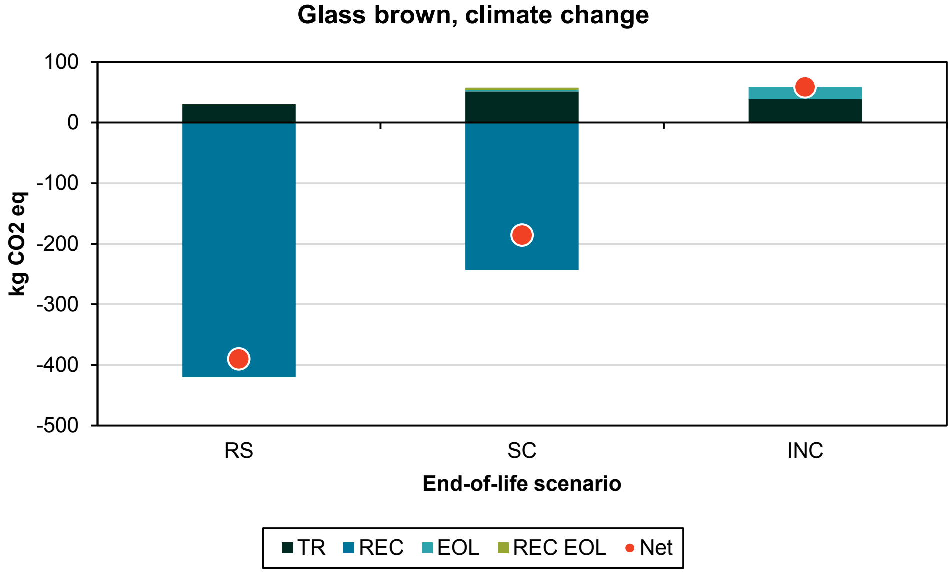


Figure 7. Characterized result scores for the brown glass beverage packaging material for the climate change impact category, expressed as kg CO_2 equivalents per reference flow. The results are provided for the three end-of-life options: return system (RS), separate collection (SC) and incineration (INC). The figure shows the contribution of the waste management phases to the final result. TR: collection and transport; REC: recycling; EOL: end-of-life, incineration of residual waste; RECEOL: incineration of residues from recycling.

As later explained in Section 7, glass production provides the lowest impacts for CC among beverage packaging materials, and therefore low CC savings when recovered. For this type of material, transportation proportionally contributes higher to the overall net result. Therefore, a close location of the sorting and recycling of this material is beneficial to increase the benefits from the recycling end-of-life scenarios, as well as limiting the burdens when residues have to be incinerated. For the assessed scenarios in this study, management of the waste beverage packaging glass was assumed to occur in Denmark.

6.4 Aluminium

Aluminium beverage packaging waste was characterized by considerably higher savings than the other material assessed, due to the avoided production of primary aluminium material obtained through the recycling end-of-life scenarios (RS and SC). The magnitude of these savings is discussed in Section 7.

For the CC impact category, RS and SC provided larger savings than INC due to the high recovery of aluminium (Figure 8). The results of RS and SC were close in magnitude due to the similar amount of material recovered in the two systems, which is related to the high technological efficiency and market response of aluminium. The same trend could be observed for all other impact categories with exception of RD. SC provided a similar result to RS for the PM impact category (-10 % difference). Incineration of aluminium results in overall environmental savings due to recycling of aluminium via the aluminium scrap, 50% of the aluminium was assumed recovered from the ashes (after oxidation and ash sorting losses).

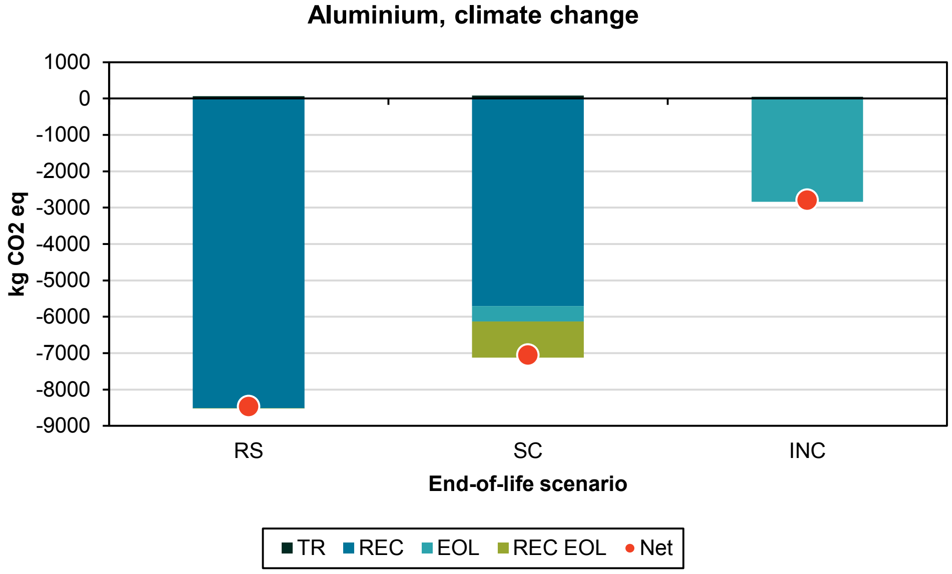


Figure 8. Characterized result scores for the aluminium beverage packaging material for the climate change impact category, expressed as kg CO_2 equivalents per reference flow. The results are provided for the three end-of-life options: return system (RS), separate collection (SC) and incineration (INC). The figure shows the contribution of the waste management phases to the final result. TR: collection and transport; REC: recycling; EOL: end-of-life, incineration of residual waste; RECEOL: incineration of residues from recycling.

6.5 Composite

The composite beverage packaging material provided the closest results between end-of-life options. As can be seen for the results for the CC impact category provided in Figure 10, results between the three assessed end-of-life options had a comparable magnitude. RS provided slightly higher savings than INC due to material recycling (9 % difference), but energy recovery via INC provided higher savings than SC. The lower savings obtained by the SC end-of-life option are due to the lower amount of material recycled via the SC system, but also to the management of residual waste and residues from the recycling process. Since recycling of cardboard provided low savings (for example in comparison with the aluminium beverage packaging material), the contribution of transport to the impacts is proportionally higher than for the plastic and metal materials. The results for RS and SC were within ±10 % difference for HTC, HTNC and FE.

INC results as the most preferable end-of-life option for most of the impact categories and with a large percent difference from RS and SC results for: OD, HTC, HTNC, PM, POF, TA, TE, ME, ET, and RDfos, due to the recovery of electricity and heat.

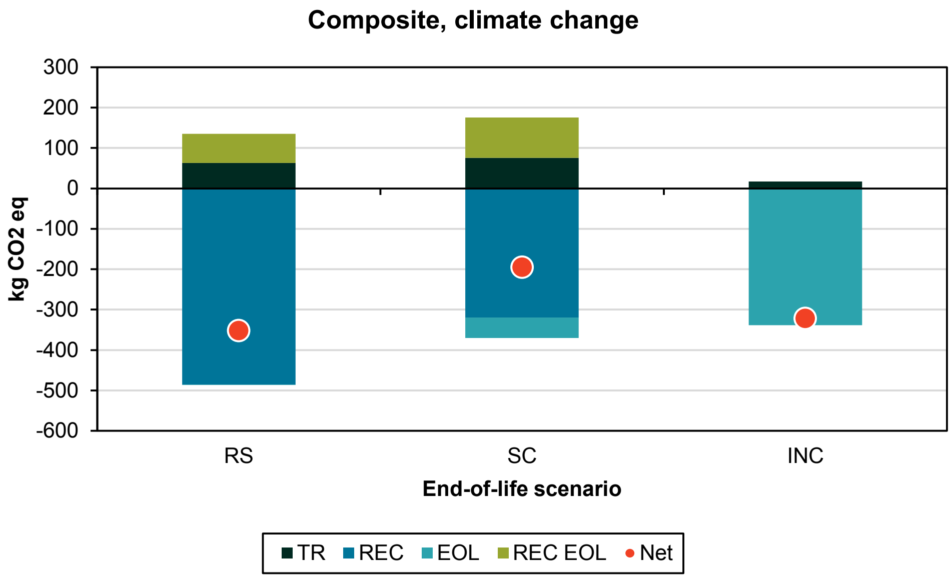


Figure 10. Characterized result scores for the composite beverage packaging material for the climate change impact category, expressed as kg CO_2 equivalents per reference flow. The results are provided for the three end-of-life options: return system (RS), separate collection (SC) and incineration (INC). The figure shows the contribution of the waste management phases to the final result. TR: collection and transport; REC: recycling; EOL: end-of-life, incineration of residual waste; RECEOL: incineration of residues from recycling.

6.6 Normalized impacts

The normalized results provide additional information on the relative significance of the indicator results. The values are given as person equivalents (PE) which corresponds to the average contribution of one person to each impact category. For all the assessed beverage packaging materials and end-of-life options, the impact categories OD, IR, POF, TA, TE, ME and FE provided the lowest absolute magnitude of the result scores. Relatively larger absolute result scores were observed for ET, RDfos and RD impact categories in general, as well as HTC for aluminium for all end-of-life options. CC was in the middle in terms of absolute magnitude of the result scores. Section 7 will discuss further the overall findings from the study.

Table 16. Normalized results for the RS end-of-life scenario, for each of the waste beverage packaging material and impact categories assessed. Results are expressed as normalized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
PET	-3.3E-01	-1.6E-03	-9.1E-01	-2.6E-01	-7.3E-01	-1.7E-02	-1.4E-01	-2.2E-01	-1.9E-01	-4.5E-01	-2.0E-01	-2.6E+00	-1.2E+00	-4.9E+00
HDPE	-1.7E-01	8.9E-04	-2.4E-01	-2.2E-02	-2.9E-01	1.2E-02	-1.4E-01	-1.5E-01	-1.1E-01	-2.5E-02	-1.2E-01	-5.3E-01	-9.9E-01	7.1E-02
Glass, clear	-4.9E-02	-8.1E-04	-1.8E-01	-5.0E-02	-3.1E-01	-7.2E-03	-8.6E-03	-3.6E-02	-5.2E-02	-1.2E-01	-1.8E-02	-5.7E-01	-7.9E-02	-1.7E+00
Glass, green	-5.6E-02	-9.5E-04	-1.9E-01	-5.7E-02	-3.3E-01	-8.3E-03	-1.2E-02	-4.3E-02	-5.9E-02	-1.2E-01	-2.4E-02	-6.6E-01	-9.5E-02	-1.7E+00
Glass, brown	-4.8E-02	-7.8E-04	-1.8E-01	-4.9E-02	-3.1E-01	-6.9E-03	-8.1E-03	-3.6E-02	-5.1E-02	-1.2E-01	-1.7E-02	-5.6E-01	-7.7E-02	-1.7E+00
Aluminium	-1.0E+00	-1.9E-02	-1.5E+01	-1.8E+00	-2.0E+00	-5.3E-01	-4.4E-01	-1.1E+00	-5.5E-01	-8.1E-01	-5.7E-01	-1.7E+01	-2.0E+00	-2.1E+00
Composite	-4.3E-02	-1.6E-03	-5.5E-02	-1.3E-01	1.7E-01	-1.4E-02	-2.0E-02	-2.0E-02	-8.3E-03	-6.4E-02	-3.8E-02	-4.3E-02	-7.2E-02	-6.7E+00

Table 17. Normalized results for the SC end-of-life scenario, for each of the waste beverage packaging material and impact categories assessed. Results are expressed as normalized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
PET	-7.3E-02	-7.9E-04	-4.1E-01	-2.1E-01	-3.9E-01	-9.4E-03	-7.6E-02	-1.6E-01	-1.2E-01	-2.5E-01	-1.2E-01	4.3E+00	-6.6E-01	-1.7E+00
HDPE	-5.7E-02	1.7E-04	-2.0E-01	-1.4E-01	-2.7E-01	4.0E-03	-1.0E-01	-1.5E-01	-1.1E-01	-9.4E-02	-1.1E-01	2.2E-01	-7.2E-01	-5.4E-03
Glass, clear	-2.3E-02	-4.1E-04	-1.1E-01	-2.2E-02	-1.8E-01	-3.9E-03	3.1E-03	-1.1E-02	-1.9E-02	-7.4E-02	5.0E-03	-2.6E-01	-3.8E-02	-1.1E+00
Glass, green	-2.8E-02	-5.0E-04	-1.2E-01	-2.7E-02	-1.9E-01	-4.7E-03	8.4E-04	-1.6E-02	-2.4E-02	-8.0E-02	8.5E-04	-3.2E-01	-5.0E-02	-1.1E+00
Glass, brown	-2.3E-02	-3.9E-04	-1.1E-01	-2.2E-02	-1.8E-01	-3.7E-03	3.3E-03	-1.1E-02	-1.9E-02	-7.4E-02	5.4E-03	-2.5E-01	-3.7E-02	-1.1E+00
Aluminium	-8.7E-01	-1.4E-02	-1.2E+01	-1.2E+00	-1.8E+00	-3.8E-01	-3.6E-01	-8.7E-01	-4.6E-01	-6.1E-01	-4.7E-01	-1.3E+01	-1.7E+00	2.3E+01
Composite	-2.4E-02	-1.4E-03	-5.9E-02	-1.3E-01	8.2E-02	-1.3E-02	-1.8E-02	-2.8E-02	-1.5E-02	-5.8E-02	-3.2E-02	3.0E-01	-8.4E-02	-8.9E+00

Table 18. Normalized results for the INC end-of-life scenario, for each of the waste beverage packaging material and impact categories assessed. Results are expressed as normalized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
PET	1.1E-01	-3.3E-03	-2.1E-01	-5.0E-01	-4.7E-01	-1.6E-02	-8.2E-02	-2.0E-01	-1.9E-01	-1.1E-01	-1.5E-01	-1.1E+00	-4.0E-01	-4.4E-01
HDPE	1.1E-01	-3.3E-03	-2.1E-01	-5.0E-01	-4.7E-01	-1.6E-02	-8.2E-02	-2.0E-01	-1.9E-01	-1.1E-01	-1.5E-01	-1.1E+00	-4.0E-01	-4.4E-01
Glass, clear	8.2E-03	2.1E-04	4.9E-03	9.4E-03	2.3E-02	1.9E-03	2.0E-02	1.9E-02	3.9E-02	3.0E-03	4.3E-02	1.1E-01	1.7E-02	-7.8E-02
Glass, green	7.1E-03	2.0E-04	2.1E-02	6.4E-03	2.0E-02	1.9E-03	1.9E-02	1.8E-02	3.7E-02	2.2E-03	4.2E-02	1.2E-01	1.5E-02	-9.1E-02
Glass, brown	7.3E-03	2.0E-04	6.3E-03	7.0E-03	2.1E-02	1.9E-03	1.9E-02	1.8E-02	3.7E-02	2.4E-03	4.2E-02	1.1E-01	1.5E-02	-8.9E-02
Aluminium	-3.4E-01	-5.5E-03	-4.7E+00	4.5E-01	-6.9E-01	-1.4E-01	-1.1E-01	-2.2E-01	-9.5E-02	-2.3E-01	-9.0E-02	-5.0E+00	-6.3E-01	-1.3E+00
Composite	-4.0E-02	-1.7E-03	-2.8E-01	-2.6E-01	-2.4E-01	-1.3E-02	-3.5E-02	-9.9E-02	-7.8E-02	-6.3E-02	-5.8E-02	-6.9E-01	-2.1E-01	-2.3E-01

7. Discussion of LCA results

This section provides a discussion of the LCIA results obtained for each of the mono-material flows. As previously explained, this section identifies the most preferable end-of-life option for the specific beverage packaging materials assessed in this study.

Moreover, since the different materials provided large differences in the magnitude of the savings from the recycling processes, this section compares the results with those from the production of materials used in the beverage packaging.

Finally, potential results are illustrated for the case where the mono-materials for all three product types are moved from the current disposal option, to the return system.

7.1 Which disposal option provides the lowest impact for each specific mono material beverage packaging types?

Section 6 identified, material by material and for each impact category, the end-of-life option providing the lowest impacts (or highest savings). The results of these analyses are summarized in Table 19. For each beverage packaging material in the rows, the Table reports which end-of-life option provided the lowest LCIA result score, for each of the impact categories listed in the columns. “RS” signifies that management via the return system had provided the lowest impacts (or highest savings), while “SC” signifies that separate collection provided the lowest impacts (or highest savings), “INC” corresponds to the cases when incineration provided the lowest impacts (or highest savings).

Management of beverage packaging waste via the return system provided the highest number of beneficial results, followed by management via incineration. The return system always resulted as the waste management option providing the lowest impacts (or highest savings) with respect to the climate change impact category. However, considering all the assessed impact categories, the most preferable end-of-life option differed according to the beverage packaging material types.

The return system (RS) was the most beneficial management option for PET, glass and aluminium. For the PET beverage packaging material, the return system provided the lowest impacts in 11 out of 14 impact categories, while for glass and aluminium RS provided the lowest impacts for all the impact categories assessed. Incineration provided a better performance for PET for the impact categories where energy recovery was more beneficial (OD, HTNC, TE). However, for PET the incineration results for the TE impact category varied only by 3 % from the return system results.

For HDPE and composite beverage packaging materials, incineration (INC) resulted as the best waste management option for 10 impact categories out of 14. In the case of HDPE, less plastic material is recycled in comparison to PET, therefore comparatively lowering the benefits from recycling. Moreover, the environmental impacts associated to the production of HDPE were the lowest among beverage packaging materials for most of the impact categories, further lowering the benefits from recycling (as explained in 7.2). At the same time, incineration allows recovering the energy content of plastic material. In the case of the composite beverage packaging material, less material was recycled (for this study only a fraction of the composite material was recyclable and the remaining part had to be disposed of), and for the majority of the impact categories recovery of energy resulted more beneficial than recycling.

Separate collection (SC) resulted as the best disposal option only in the case of composite beverage packaging material, for resource depletion. However, for this impact category SC provided the largest benefits by recovering energy from incineration of the residues from recycling, rather than from material recovery. Although SC is rarely displayed in Table 19, it is relevant to mention that results for the SC end-of-life provided the second best results for most of the dark green fields (which represent RS). RS end-of-life represents an improved SC and the end-of-life options therefore are likely to have advantages over INC in the same impact categories, but with RS always providing a better performance than SC. Such results can be observed from the characterized results scores presented in Tables 13-15.

Table 19. Summary of the end-of-life options providing the lowest impacts (or highest savings) for each waste beverage packaging material in the rows and corresponding assessed impact category in the columns. RS: return system (Dark green); SC: separate collection (Blue); INC: incineration (Light green). The colour code is meant to help identify the different disposal options.

Beverage packaging type	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
PET	RS	INC	RS	INC	RS	RS	RS	RS	INC	RS	RS	RS	RS	RS
HDPE	RS	INC	RS	INC	INC	INC	RS	INC	INC	INC	INC	INC	RS	INC
Glass, clear	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS
Glass, green	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS
Glass, brown	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS
Aluminium	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS	RS
Composite	RS	INC	INC	INC	INC	RS	INC	INC	INC	RS	INC	INC	INC	SC

7.2 Influence of data and assumptions on the results

The physico-chemical material composition used for modelling input-specific emissions in the EASETECH LCA model allowed retrieving generic impacts for material groups, such as plastic, glass, metal and composite. The emissions mostly contributed to impacts to atmosphere via the incineration process, especially for climate change for plastic materials and human toxicity for metals.

The large transportation distances assumed were considered conservative estimates. Impacts related to transport provided a relatively limited contribution to the overall LCA results for all the waste beverage material types assessed. The relative contribution to the results for transport was higher for beverage packaging materials that obtained lower benefits from recycling (avoided virgin production causing lower environmental impacts), such as HDPE and glass.

The sorting efficiencies for the separate collection system assumed for coarse and fine sorting between Denmark and Europe could be higher than actual efficiencies. However, this assumption influenced only the amount of material recovered by the separate collection system, but would not influence the results in terms of best waste management option for each beverage packaging material type, since separate collection did not appear as the best waste management option for any of the beverage packaging materials assessed.

High quality recycling was modelled by increasing the recycling efficiency (lower recovery losses in the process) of the “normal quality” recycling process. The increased efficiencies, called “high-quality” recycling, resulted being very high, as it can be seen from Table 8. Nevertheless, if the return system had been associated with the same normal-quality recycling efficiencies of the separate collection one (Tables 9 and 10), it would still have provided larger environmental benefits than separate collection due to the larger amount material collected through the return system. In the case where the return system was associated with lower recycling efficiencies, incineration would provide the lowest impacts in a number of impact categories for PET, and in all impact categories for composite. This emphasizes the importance of maintaining a high quality in the recycling. The most preferable end-of-life options would remain unchanged for the remaining waste beverage packaging material types. Therefore, high recycling efficiencies are particularly important for PET and composite beverage packaging materials. Lower recycling efficiencies would also entail, for all material types, that the net environmental impact associated would increase, and that the waste management system could balance less of the impacts arising from the production of the beverage packaging materials. This finding highlights the importance of a recovery system that ensures high actual recycling rates, and not just high collection rates.

7.3 What are the impacts connected to the production of the beverage packaging materials?

As described at the beginning of Section 6, the LCIA results differed greatly in magnitude between beverage packaging material types. This was due to the fact that the beverage packaging material types are associated to different environmental impacts related to their production. Therefore, while the waste management part as collection, transport and incineration may have comparable impacts, the savings from the recycling part of the waste management system provided different magnitudes, with the highest savings associated to materials with the highest environmental impact from their material production.

This section provides in Table 20 the LCIA results for the impacts associated with the production of materials for each of the beverage packaging material type assessed. The results are provided per kg of produced material. The details about the chosen inventories for each material type are provided in Appendix B. The colour scale goes from red (highest impact) to white (lowest impact) for each column of Table 20 (impact category). Table 20 provides only impact scores, since the values are related to the material production only.

Aluminium material production is characterized by the highest impacts in all impact categories with exception of ozone depletion and resource depletion. For this reason, the aluminium beverage packaging material provides the highest savings when recycled among the assessed beverage packaging waste types. On the other hand, glass production (clear, green and brown) and HDPE provide the lowest production impacts. Glass production provides the lowest impacts for climate change, photochemical ozone formation, ecosystem toxicity and resource depletion. HDPE provides the lowest impacts for the remaining impact categories, which are ozone depletion, human toxicity, cancer and non-cancer effects, particulate matter, ionizing radiation, terrestrial acidification and eutrophication, freshwater and marine eutrophication, and resource depletion. Due to the low impacts associated with their production, glass and HDPE beverage packaging material provide the lowest savings in comparison with the material types assessed. Moreover, in the case of HDPE, the amount of recovered material for the return and separate collection systems was lower than for glass, which contributed in reducing the savings from recovery of such material.

For composite material, the environmental impacts associated to its production were rather high in comparison to other beverage packaging materials. However, the recovery of composite via the return and separate collection systems provided limited savings for the lower amount of material recovered (which is limited to the carton part of the packaging material) and, mostly, because the recovered linerboard is associated to very low environmental impacts from material production.

It should be noted, however, that the environmental impacts in Table 20 refer to the beverage packaging material only (the same material substituted in the recycling) and not the beverage packaging product: in order to produce, package and distribute the product, higher environmental impacts are expected, for the material and energy required in such processes. Furthermore it should be kept in mind that the beverage packaging manufactured from different materials will have different weights, meaning that Table 20 cannot be used directly for choosing which material should be preferred in the production phase. It was chosen not to include results per beverage unit, as this could lead to a belief that the results were directly comparable across materials. Since there are large variation in products within a material (e.g. weight, shape and colour of a PET bottle), and the cost to produce the specific product from the raw material varies, this comparison was not included, as this would require a full product LCA of the considered products which is outside the scope of the study.

Table 20. Characterized results for the environmental impact due to material production for each beverage packaging material types assessed. The results are provided per kg of produced material. The details about the chosen inventories for each material type are provided in Appendix B. The colour scale goes from red (highest impact) to white (lowest impact) for each column of the table (impact category).

Beverage packag-ing material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	kg CO_2 eq	kg CFC11 eq	CTUh	CTUh	kg PM2.5 eq	kBq U235 eq	kg NMVOC	mol H+ eq	mol N eq	kg P eq	kg N eq	CTUe	MJ	kg Sb eq
PET	3.3E+00	1.3E-07	5.4E-08	3.6E-07	2.5E-03	4.5E-02	9.5E-03	1.4E-02	2.7E-02	3.2E-04	2.4E-03	2.5E+00	8.7E+01	1.8E-04
HDPE	2.0E+00	1.3E-08	1.6E-08	2.3E-08	1.0E-03	4.2E-03	9.1E-03	8.4E-03	1.5E-02	5.0E-06	1.4E-03	1.0E+00	7.1E+01	1.7E-06
Glass, clear	1.4E+00	1.2E-07	1.9E-08	2.1E-07	2.1E-03	2.4E-02	5.1E-03	1.3E-02	2.4E-02	1.4E-04	1.7E-03	8.9E-01	2.3E+01	7.4E-05
Glass, green	1.5E+00	1.3E-07	1.8E-08	2.2E-07	2.0E-03	2.9E-02	5.3E-03	1.2E-02	2.4E-02	1.4E-04	1.7E-03	1.0E+00	2.4E+01	7.5E-05
Glass, brown	1.4E+00	1.3E-07	1.8E-08	2.1E-07	2.0E-03	2.8E-02	5.2E-03	1.2E-02	2.4E-02	1.4E-04	1.7E-03	9.7E-01	2.4E+01	7.4E-05
Alumini-um	1.0E+01	6.8E-07	8.4E-07	2.1E-06	7.3E-03	3.8E-01	3.4E-02	7.4E-02	9.1E-02	5.2E-04	7.7E-03	1.2E+01	1.5E+02	8.0E-05
Compo-site	2.6E+00	6.5E-06	6.8E-08	4.3E-07	3.8E-03	2.8E-02	1.0E-02	1.5E-02	2.8E-02	1.8E-04	3.7E-03	2.0E+00	5.0E+01	3.7E-05

7.4 What are the environmental impacts of the disposal of these products via the return system in Denmark?

This section illustrates the potential effects of a full implementation for beverage packaging materials of glass, plastic and aluminium for juice and milk products, assuming they were included in the current return system. The results are only potential since they were obtained by combining the LCA results for the mono-materials, with the information from Section 2 on amounts of beverage packaging and current efficiencies in the waste management system. The purpose is only to illustrate the potential magnitude of amounts and environmental impacts by scaling the results for the mono-materials.

The section first presents the three potential scenarios that were considered, then present and discuss the associated amounts treated for the disposal options, finally potential impacts associated to each scenario are displayed and discussed.

7.4.1 Illustrative scenarios

The calculation was done by assigning weights of generated beverage packaging waste for each material type, and subdividing them between the RS, SC and INC end-of-life options using weight-based percentages for each scenario. This model configuration was particularly useful in order to calculate and illustrate potential future management scenarios for waste beverage packaging material. The scenarios were calculated based on The Nielsen Company (2017) data previously presented in Table 2, Section 2. The calculations were done for the combined juice and milk product packaging amount (PET, HDPE, aluminium and glass), as well as separately for the juice and the milk products for which the results are included in Appendix C. The three scenarios are illustrated in Figure 11 as follows:

- **Scenario 1** - Baseline: Current practice for packaging material handling with separate collection and recycling, with efficiencies based on Miljøstyrelsen, 2018, as described in section 2.3. As defined in the Introduction, this scenario describes the current situation where beverage packaging products are not collected via the return system (RS), although other beverage packaging products with the same material already are. For these beverage packaging products, it is assumed that 23 % plastic, 50 % aluminium and 66 % glass is collected for recycling via separate collection (SC), the remaining material is sent to incineration together with the residual waste. The recycling is all considered recycled at normal quality.
- **Scenario 2**: All materials (glass, PET, HDPE and aluminium) are considered to be included in the current return system. A 90 % participation rate is assumed like in the current system. The last 10 % is considered split between recycling and incineration with the same distribution as in Scenario 1.
- **Scenario 3**: Stakeholders have suggested that inclusion of new products in the return system could make producers shift from packaging materials that will be a part of the expanded return system to composite materials that will not be included in the return system. Scenario 3 therefore assumes that 50 % of the packaging to be included in the return system is composite material and the remaining 50 % are managed like in Scenario 2. Since the average weight of the composite packaging are not the same as the other packaging, the amount of composite was calculated based on the difference in weight per volume. The composite material is 100% sent to incineration as they are not currently being managed by Dansk Retursystem A/S.

The efficiencies used in the scenarios are indicative of current waste management in Denmark. The values can be higher or lower depending on the specific waste management system in different municipalities and should therefore be understood as examples of what the result could be from a full implementation. Currently, there are no municipalities collecting composite material for recycling, even though there have been tests in a few municipalities. Based on this, the current management route (incineration) was selected.

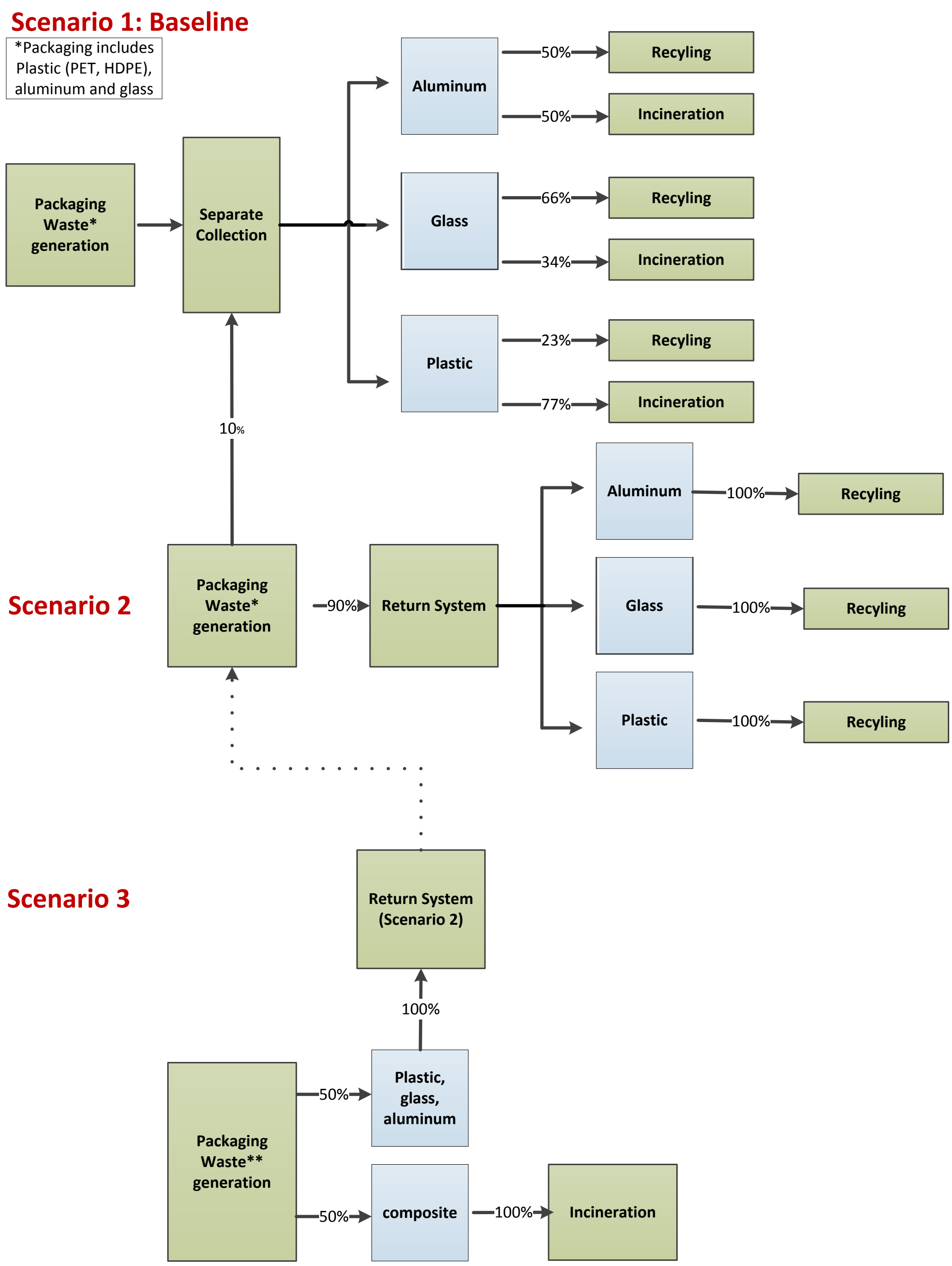


Figure 11. The three scenarios modelled: 1) Baseline, 2) 90% Return system, the rest as baseline. 3) 50% Composite material to incineration, the rest as baseline.

7.4.2 Amounts for different treatment options in the three scenarios

Figure 12 illustrates the distribution of the amount of packaging for the three scenarios. The total amount for Scenario 1 and 2 are the same, but due to the higher return rate, the results show how a larger amount ends up destined for recycling. Due to the high weight of individual glass containers, glass beverage packaging waste makes up a very large share of the overall materials (91% of SC, and 81% for RS). When looking at the three different product groups assessed (Appendix C), the overall distribution of the columns is similar, but the milk products have a larger share of glass than the juice products. The amounts in Scenario 3 are considerably lower than for the other scenarios, this is mainly due to the difference between glass and composite packaging where the composite containers are considerably lighter. As the results in Section 6 and 7 indicated this is though not necessarily the same as high environmental savings, as glass does not have as high environmental impacts from production, which is discussed in 7.3.3.

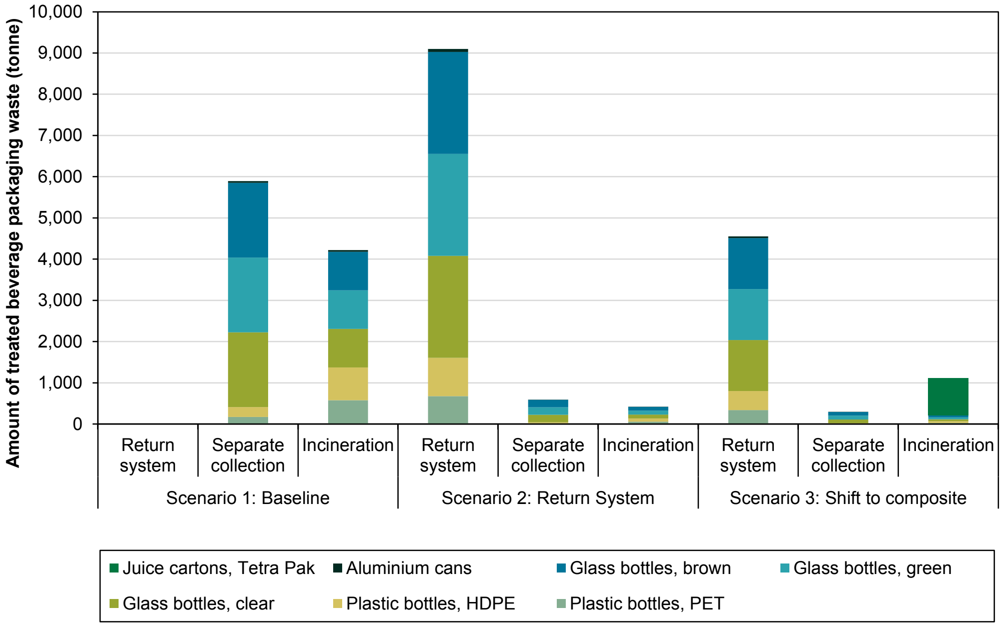


Figure 12. The amounts for Scenario 1 the current system with 25 % separate collection of plastic, 50 % separate collection of metals, and 75 % separate collection of glass.

7.4.3 Environmental impacts of the three different treatment options in the three scenarios

In Table 21 the normalized results for the 14 different potential environmental impacts are shown. The values are given as person equivalents (PE) which corresponds to the average contribution of one person to each impact category. To make comparisons easier Table 22 shows the difference between Scenario 1 and 2, and Scenario 1 and 3, respectively.

Overall the results show that Scenario 2 with expansion of the return system could lead to improvements in 13 out of 14 impact categories, and only a slightly worse impact in human toxicity non-cancer. The largest improvement was seen for climate change with 3048 % change in savings in comparison to the low savings from the baseline scenario (Scenario 1), which corresponds to a net reduction of 6600 ton CO_2-equivalents.

The scenario with composite packaging has less environmental impacts where the change leads to lower net impact. In this case there would only be an improvement in environmental

performance in 12 impact categories with a change of -4 to -1608 %, whereas there would be a larger impact in two impact categories with a change of 18-29 %. The categories, where the composite materials leads to lower impacts, are in general with a larger reduction in person equivalents, and furthermore are the characterization factors for the categories with a low or no improvement from the change (Ozone depletion and Human Toxicity) surrounded by a higher uncertainty. This however, highlights that, if including more product types in the return system, the overall improvement will depend on what changes might happen in the packaging materials being used.
The results are similar when looking at the three different product types (Appendix C). Overall the return system is still the best scenario. For juice products the benefits are even higher than the benefits when comparing the separate collection today, with the return system, but the scenario with composite materials show that this will be considerably worse than for the total material.

It should be noted that these results should not be used for deciding which packaging material to be used, as they do not consist of a full product LCA, but only look at the disposal phase. It is furthermore important to be aware that the amounts in the above scenarios are only potentials, which are created on basis of potential management strategies and sorting efficiencies. Since these amounts besides the sorting and legislations will be influenced by consumer preferences, and producer choices, the scenarios should be understood as illustrative examples, and not taken as a full LCA with all the requirements for other mechanisms that should be taken into account then. Other scenarios can easily be created by changing the efficiencies and management strategies for the different packaging materials.

Table 21. Comparison of Scenario 1 (Baseline), Scenario 2 (return system), and Scenario 3 (50 % shift to composite materials, and 50 % return system). Values are given as person equivalents (PE)

Impact category	Scenario 1 (PE)	Scenario 2 (PE)	Scenario 3 (PE)
Climate change	-27	-843	-457
Ozone depletion	-7	-9	-6
Human toxicity, cancer effects	-1643	-3520	-2008
Human toxicity, non-cancer effects	-892	-804	-634
Particulate matter/Respiratory inorganics	-1778	-3438	-1932
Ionizing radiation, human health	-60	-101	-62
Photochemical ozone formation, human health	-98	-333	-198
Terrestrial acidification	-398	-692	-436
Eutrophication terrestrial	-331	-704	-423
Eutrophication freshwater	-648	-1333	-723
Eutrophication marine	-134	-452	-278
Ecotoxicity freshwater	-2588	-8162	-4701
Resources, depletion of abiotic resources, fossil	-1096	-2610	-1494
Resources, depletion of abiotic resources, elements	-6258	-16517	-8470

Table 22. Comparison of changes from Scenario 1 (Baseline) to Scenario 2 (return system) and Scenario 3 (50 % shift to composite materials, and 50 % return system) respectively. A positive value is where Scenario 1 has the lowest comparative impact, and a negative value means that Scenario 2 and 3 leads to lower comparative impacts.

Impact category	Unit	S1:S2	S1:S3
Climate change	%	-3048	-1608
Ozone depletion	%	-20	18
Human toxicity, cancer effects	%	-114	-22
Human toxicity, non-cancer effects	%	10	29
Particulate matter/Respiratory inorganics	%	-93	-9
Ionizing radiation, human health	%	-69	-4
Photochemical ozone formation, human health	%	-239	-101
Terrestrial acidification	%	-74	-10
Eutrophication terrestrial	%	-113	-28
Eutrophication freshwater	%	-106	-12
Eutrophication marine	%	-237	-107
Ecotoxicity freshwater	%	-215	-82
Resources, depletion of abiotic resources, fossil	%	-138	-36
Resources, depletion of abiotic resources, elements	%	-164	-35

8. Conclusions

The study assessed the environmental impacts of alternatives for the management of beverage packaging waste. The study compared the environmental performance of the following options:

- High quality recycling via the deposit and return system;
- Collection, sorting and recycling via the current system for recyclables;
- Incineration within the residual waste stream.

In general, the deposit and return system allowed higher collection efficiencies, as well as material recovery, than the separate collection and recycling. Moreover, the return system facilitated higher quality recycling for food grade material. PET, glass, and aluminium were the materials with the highest recovery via the return system. The recovery efficiency of the return system was always higher than the recovery efficiency of the separate collection for the same beverage packaging waste material.

The LCA results were used to identify the waste management option providing the lowest impacts for each of the waste beverage packaging materials assessed, over a range of environmental indicators. Considering climate change, the return system provided the lowest impacts for all materials. For PET and aluminium the return system provided lowest environmental indicators for respectively 11 and 10 of the assessed environmental indicators, whereas for glass it was the case for all environmental indicators. For HDPE and composite beverage packaging materials, incineration resulted being the waste management solution providing the lowest impacts for a number of the environmental indicators. The reason for this is the lower environmental benefit associated with the recycling of these materials, in comparison to incineration with energy recovery, albeit being dependent on the specific assumptions and impact categories. It is important to mention that, in all the impact categories where the return system was better than incineration, the second best disposal option was separate collection. Nonetheless, high recycling efficiencies are important as lower recycling efficiencies would also entail, for all material types, that the net environmental impact associated would increase, and that the waste management system could balance less of the impacts arising from the production of the beverage packaging materials. This finding highlights the importance of a recovery system that ensures high actual recycling rates, and not just high collection rates.

The LCA results for the best disposal option differed in magnitude because materials with high environmental production impacts are associated with high benefits when recycled, such as aluminium. For this reason, we compared the LCA results with the impacts connected to the production of the different beverage packaging materials. Aluminium was found to be the material with the highest overall impacts, why it gives the largest savings per ton when recycled. PET have higher material production cost than HDPE, why this also leads to the higher savings when recycled. Glass is per tonne the material with the lowest impact. These values should though not be used alone, but always be considered in relationship to the amounts of the different materials that are being disposed (Aluminium being the lowest, glass being the highest). Finally they can not be used for identifying used directly for choosing which material should be preferred in the production phase, as it only includes the production of the material itself and no other functionalities.

The illustrative scenario examples indicated that managing all waste by the return system (with the current efficiencies) would lead to improvements in 13 out of 14 impact categories, in comparison to the scenario with disposal via separate collection as it is the case today. The scenarios also showed that, if composite materials are used in some packaging to avoid being managed in the return system, the improvement in environmental impacts from the disposal of the packaging would not be as high, because the composite materials are currently not managed by the return system, nor collected for recycling in any Danish municipalities.

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Appendix A. Life Cycle Inventories (LCIs)

This section provides the data and corresponding references utilized for the present LCA study.

Table A1. Material composition used for each waste beverage packaging material

Scenario	Material	Material composition used
PET	Plastic, PET	Soft plastic (Riber et al., 2009)
HDPE	Plastic, HDPE	Soft plastic (Riber et al., 2009)
Glass, clear	Glass, clear	Clear glass (Riber et al., 2009)
Glass, green	Glass, green	Green glass (Riber et al., 2009)
Glass, brown	Glass, brown	Brown glass (Riber et al., 2009)
Aluminium	Metal, aluminium	Aluminium foil and containers (Riber et al., 2009)
Composite	Composite	5 % Aluminium foil and containers (Riber et al., 2009)
		20 % Soft plastic (Riber et al., 2009)
		75 % Paper and carton containers (Riber et al., 2009)

Table A2. Material composition used for the impurities. The same impurities with the same amounts were assumed for all the waste beverage packaging material scenarios.

Impurity	Material composition used	Amount (kg/ton)
Hard plastic	(Riber et al., 2009)	0.1429
Ash	(Riber et al., 2009)	0.1429
Cigarette butts	(Riber et al., 2009)	0.1429
Dirty paper	(Riber et al., 2009)	0.1429
Aluminium foil and containers	(Riber et al., 2009)	0.1429
Kitchen towels	(Riber et al., 2009)	0.1429
Soft plastic	(Riber et al., 2009)	0.1429

Table A3. Transportation distances and processes used to model transportation utilized in this LCA study.

End-of-life scenarios	Transportation	Ecoinvent process (v 3.4, consequential)	Distance (km)
RS	Collection of recyclables in DK	Market group for diesel; RER	Modelled as fuel consumption: X* L/kg
RS, SC	Recyclables from sorting in DK to recycling in EU	Transport, freight, lorry 16-32 metric ton, EURO6; RER	300**
SC	Collected recyclables to sorting in DK	Municipal waste collection service by 21 metric ton lorry; CH	110
INC, SC	Collection of waste	Municipal waste collection service by 21 metric ton lorry; CH	10
INC, RS, SC	Transport to incineration in DK	Transport, freight, lorry 16-32 metric ton, EURO6; RER	10
INC, RS, SC	Transport fly ash from DK to recycling in EU	Transport, freight, lorry 16-32 metric ton, EURO6; RER	500
INC, RS, SC	Transport of iron scrap from DK to recycling in EU	Transport, freight, lorry 16-32 metric ton, EURO6; RER	200
INC, RS, SC	Transport of aluminium scrap from DK to recycling in EU	Transport, freight, lorry 16-32 metric ton, EURO6; RER	200
INC, RS, SC	Transport of bottom ash to recycling in DK	Transport, freight, lorry 16-32 metric ton, EURO6; RER	100

* The value used for the modelling was requested not to be published.

** 110 km for glass, which was set to occur in Denmark

Table A4. Return system: fine sorting in Denmark before shipping sorted materials abroad for recycling. Mass balance.

Scenario	Material fraction	Sorted high quality (%)	Sorted lower quality (%)	Residues (%)
PET	Plastic bottles	97.7%	2.2%	0.1%
HDPE	Plastic bottles	97.7%	2.2%	0.1%
Brown glass	Brown glass	97.7%	2.2%	0.1%
Clear glass	Clear glass	97.7%	2.2%	0.1%
Green glass	Green glass	97.7%	2.2%	0.1%
Aluminium	Beverage cans (aluminium)	97.7%	2.2%	0.1%
All	Hard plastic	0.0%	0.0%	100.0%
All	Ash	0.0%	0.0%	100.0%
All	Cigarette butts	0.0%	0.0%	100.0%
All	Dirty paper	0.0%	0.0%	100.0%
All	Aluminium foil and containers	0.0%	0.0%	100.0%
All	Kitchen towels	0.0%	0.0%	100.0%
All	Soft plastic	0.0%	0.0%	100.0%

Table A5. Return system: fine sorting in Denmark before shipping sorted materials abroad for recycling. Energy requirements.

Ecoinvent process name (v 3.4, consequential)	Amount	Unit	Comment
Marginal electricity, TemaNord 2016:537, DEPA, DK, 2017	X	kWh/kg Total Wet Weight	Retursystem, 2017

*The value used for the modelling was requested not to be published.

Table A6. Mass balance for coarse sorting in Denmark, separate collection. Data on sorting efficiencies for the waste beverage packaging material were retrieved from COWI (2017).

Scenario	Material fraction	Sorted (%)	Residues (%)
PET	Plastic bottles	85.0%	15.0%
HDPE	Plastic bottles	85.0%	15.0%
Brown glass	Brown glass	85.0%	15.0%
Clear glass	Clear glass	85.0%	15.0%
Green glass	Green glass	85.0%	15.0%
Aluminium	Beverage cans (aluminium)	85.0%	15.0%
All	Hard plastic	10.0%	90.0%
All	Ash	10.0%	90.0%
All	Cigarette butts	10.0%	90.0%
All	Dirty paper	10.0%	90.0%
All	Aluminium foil and containers	10.0%	90.0%
All	Kitchen towels	10.0%	90.0%
All	Soft plastic	10.0%	90.0%

Table A7. Energy and material requirements, coarse sorting in Denmark, separate collection. Data on material and energy requirements were retrieved from COWI (2017). Diesel density: 0.832 kg/L.

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
Marginal electricity, TemaNord 2016:537, DEPA, DK, 2017	0.02	kWh/kg Total Wet Weight
Market group for diesel; RER	1.4/1000*0.832	kg/kg Total Wet Weight

Table A8. Mass balance for fine sorting in Europe, separate collection. Data on sorting efficiencies for the waste beverage packaging material were assumed similar to those of Denmark retrieved from COWI (2017).

Scenario	Material fraction	Sorted (%)	Residues (%)
PET	Plastic bottles	85.0%	15.0%
HDPE	Plastic bottles	85.0%	15.0%
Brown glass	Brown glass	85.0%	15.0%
Clear glass	Clear glass	85.0%	15.0%
Green glass	Green glass	85.0%	15.0%
Aluminium	Beverage cans (aluminium)	85.0%	15.0%
All	Hard plastic	0.0%	100.0%
All	Ash	0.0%	100.0%
All	Cigarette butts	0.0%	100.0%
All	Dirty paper	0.0%	100.0%
All	Aluminium foil and containers	0.0%	100.0%
All	Kitchen towels	0.0%	100.0%
All	Soft plastic	0.0%	100.0%

Table A9. Energy and material requirements, fine sorting in Europe, separate collection. Data on material and energy requirements for fine sorting were assumed similar to those of Denmark retrieved from COWI (2017).
Diesel density: 0.832 kg/L.

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
Marginal electricity, TemaNord 2016:537, DEPA, DK, 2017	0.036	kWh/kg Total Wet Weight
Market group for diesel; RER	1.2/1000*0.832	kg/kg Total Wet Weight

Table A10. Material and energy requirements, PET recycling (Giugliano et al., 2011; Perugini et al., 2005, Rigamonti et al., 2014).

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
Market group for electricity, high voltage; RER	0.32	kWh/kg Total Wet Weight recycled PET
Market group for tap water; RER	2.96	kg/kg Total Wet Weight recycled PET
Market for sodium hydroxide, without water, in 50% solution state; GLO	0.003	kg/kg Total Wet Weight recycled PET
Steam production, in chemical industry; RER	0.93	kg/kg Total Wet Weight recycled PET

Table A11. Material and energy requirements, HDPE recycling (Giugliano et al., 2011; Perugini et al., 2005, Rigamonti et al., 2014).

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
Market group for electricity, high voltage; RER	0.44	kWh/kg Total Wet Weight recycled HDPE
Market group for tap water; RER	1.78	kg/kg Total Wet Weight recycled HDPE
Steam production, in chemical industry; RER	0.18	kg/kg Total Wet Weight recycled HDPE

Table A12. Material and energy requirements, glass recycling, according to British Glass (2004), European Commission (2012), Rigamonti et al. (2010, 2009).

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
Market group for electricity, high voltage; RER	0.0184	kWh/kg Total Wet Weight
Packaging glass production, white; RER w/o CH+DE	0.19	kg/kg Total Wet Weight
Steam production, in chemical industry; RER	1.89	kg/kg Total Wet Weight

Table A13. Process-specific emissions, glass recycling, according to British Glass (2004), European Commission (2012), Rigamonti et al. (2010, 2009).

Name	Compartment	Sub compartment	Amount	Unit	Per
Particulates, < 2.5 um	air	unspecified	0.25/1000	kg	kg Total Wet Weight
Particulates, > 2.5 um, and < 10um	air	unspecified	0.013/1000	kg	kg Total Wet Weight
Particulates, > 10 um	air	unspecified	0.037/1000	kg	kg Total Wet Weight
Carbon dioxide, fossil	air	unspecified	32/1000	kg	kg Total Wet Weight
Nitrogen oxides	air	unspecified	2/1000	kg	kg Total Wet Weight
Sulphur dioxide	air	unspecified	2.7/1000	kg	kg Total Wet Weight
Hydrogen chloride	air	unspecified	0.05/1000	kg	kg Total Wet Weight
Hydrogen fluoride	air	unspecified	0.02/1000	kg	kg Total Wet Weight
Cadmium	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Arsenic	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Cobalt	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Nickel	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Selenium	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Antimony	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Lead	air	unspecified	7.72E-07	kg	kg Total Wet Weight
Chromium	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Copper	air	unspecified	6.74E-07	kg	kg Total Wet Weight
Manganese	air	unspecified	6.74E-07	kg	kg Total Wet Weight

Table A14. Material and energy requirements, aluminium recycling, according to Rigamonti et al. (2009)

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
Market group for electricity, high voltage; RER	0.01	kWh/kg Total Wet Weight
Steam production, in chemical industry; RER	1.46	kg/kg Total Wet Weight

Table A15. Process-specific emissions, aluminium recycling, according to Rigamonti et al. (2009)

Name	Com-partment	Sub com-partment	Amount	Unit	Per
Particulates, < 2.5 um	air	unspecified	0.000029*0.25	kg	kg Total Wet Weight
Particulates, > 2.5 um, and < 10um	air	unspecified	0.000029*0.75	kg	kg Total Wet Weight
Lead	air	unspecified	2E-08	kg	kg Total Wet Weight
Cadmium	air	unspecified	7.6E-10	kg	kg Total Wet Weight
Particulates, > 10 um	air	unspecified	9E-06	kg	kg Total Wet Weight
Arsenic	air	unspecified	2E-09	kg	kg Total Wet Weight
Antimony	air	unspecified	7.6E-10	kg	kg Total Wet Weight
Chlorine	air	unspecified	8E-08	kg	kg Total Wet Weight
Fluorine	air	unspecified	8E-08	kg	kg Total Wet Weight
Hydrogen chloride	air	unspecified	4E-08	kg	kg Total Wet Weight
Hydrogen fluoride	air	unspecified	5.2E-07	kg	kg Total Wet Weight
Hydrogen sulphide	air	unspecified	2.8E-06	kg	kg Total Wet Weight
Nitrogen oxides	air	unspecified	0.00047	kg	kg Total Wet Weight
Sulphur dioxide	air	unspecified	0.00085	kg	kg Total Wet Weight
Carbon monoxide, non-fossil	air	unspecified	0.00187	kg	kg Total Wet Weight
Ammonia	air	unspecified	1E-05	kg	kg Total Wet Weight
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	air	unspecified	6.8E-11	kg	kg Total Wet Weight
Polychlorinated biphenyls	air	unspecified	7.7E-09	kg	kg Total Wet Weight
PAH, polycyclic aromatic hydrocarbons	air	unspecified	1.89E-07	kg	kg Total Wet Weight
Hydrocarbons, chlorinated	air	unspecified	0	kg	kg Total Wet Weight
Benzene, hexachloro-	air	unspecified	1.3E-08	kg	kg Total Wet Weight
NMVOC, non-methane volatile organic compounds, unspecified origin	air	unspecified	0.001	kg	kg Total Wet Weight

Table A16. Material and energy requirements, composite (aluminium foil, plastic foil and carton) beverage packaging recycling (Banar and Cokaygil, 2008).

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
Market group for electricity, high voltage; RER	0.485	kWh/kg Total Wet Weight

Table A17. End-of-life of residues from recycling: Ecoinvent processes.

Scenario	Ecoinvent process name (v 3.4, consequential)
PET	Treatment of waste polyethylene terephthalate, municipal incineration; Europe without Switzerland
HDPE	Treatment of waste polyethylene, municipal incineration; Europe without Switzerland
Clear glass	Treatment of waste glass, municipal incineration; Europe without Switzerland
Green glass	Treatment of waste glass, municipal incineration; Europe without Switzerland
Brown glass	Treatment of waste glass, municipal incineration; Europe without Switzerland
Aluminium	Treatment of scrap aluminium, municipal incineration; Europe without Switzerland
Composite	Treatment of municipal solid waste, municipal incineration with fly ash extraction; CH

Table A18. Material and energy requirements and corresponding Ecoinvent processes used for the modelling of the incinerator technology. Material and energy requirements were obtained from Vestforbrænding (2013). Electricity recovery was considered 22 %, heat recovery 73 %. Please refer to Appendix B for the marginal electricity and heat utilized.

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
quicklime production, milled, packed; CH	0.00034	kg/kg Total Wet Weight
market for ammonia, liquid; RER	0.00153	kg/kg Total Wet Weight
activated carbon production, granular from hard coal; RER	0.00104	kg/kg Total Wet Weight
market for tap water; Europe without Switzerland	0.397	kg/kg Total Wet Weight
hydrochloric acid production, from the reaction of hydrogen with chlorine; RER	5.60E-06	kg/kg Total Wet Weight
market for sodium hydroxide, without water, in 50% solution state; GLO	2.40E-05	kg/kg Total Wet Weight
market for calcium carbonate, precipitated; GLO	0.00567	kg/kg Total Wet Weight
Marginal electricity, see Appendix B	-0.22/3.6	kWh/MJ
Marginal heat, see Appendix B	-0.73	MJ/MJ

Table A19. Emissions to the air, unspecified, Vestforbrænding (2013).

Elementary exchange	Amount	Unit
Carbon monoxide	3.30E-02	kg/kg Total Wet Weight
Dust	4.06E-03	kg/kg Total Wet Weight
HCl	6.58E-03	kg/kg Total Wet Weight
HF	2.70E-04	kg/kg Total Wet Weight
Manganese	1.12E-02	kg/kg Total Wet Weight
NH_3	4.31E-03	kg/kg Total Wet Weight
Nickel	3.47E-06	kg/kg Total Wet Weight
Nitrogen Oxides (NOx)	5.49E-01	kg/kg Total Wet Weight
PAH (B[a]P-eq)	4.31E-06	kg/kg Total Wet Weight
PCDD/F	1.80E-11	kg/kg Total Wet Weight
SO_2/SO_3	1.08E-02	kg/kg Total Wet Weight

Table A20. Transfer coefficients to air emissions from input composition, Vestforbrænding (2013).

Parameter	Unit	Value
Hg	% Hg in	0.7476
Cd	% Cd in	0.0064
Pb	% Pb in	0.0008
Cr	% Cr in	0.0394
Cu	% Cu in	0.003
As	% As in	0.012
Ni	% Ni in	0.033
Sb	%Sb in	0.119

Table A21. Transfer coefficients for degradation and residues for the soft plastic material fraction, Vestforbrænding (2013).

Fraction name	Degradation			Fly ash			Scrap metals			Bottom ash		
	Water (%)	VS (%TS)	Ash (%TS)	Water (%)	VS (%TS)	Ash (%TS)	Water (%)	VS (%TS)	Ash (%TS)	Water (%)	VS (%TS)	Ash (%TS)
Soft plastic	100	99.9	0	0	0	12.6	0	0	0	0	0.1	87.4

Table A22. Emissions to water, Vestforbrænding incinerator.

Elementary exchange	Compartment	Value	Unit
Antimony	water	8.80E-06	kg/kg Total Wet Weight
Arsenic	water	5.60E-07	kg/kg Total Wet Weight
Barium	water	7.20E-06	kg/kg Total Wet Weight
Cadmium	water	9.67E-08	kg/kg Total Wet Weight
Calcium	water	4.16E-02	kg/kg Total Wet Weight
Chloride	water	4.11E+00	kg/kg Total Wet Weight
Chromium	water	4.48E-06	kg/kg Total Wet Weight
Cobalt	water	4.00E-08	kg/kg Total Wet Weight
Copper	water	2.00E-04	kg/kg Total Wet Weight
Fluoride	water	2.08E-03	kg/kg Total Wet Weight
Iron	water	4.00E-05	kg/kg Total Wet Weight
Lead	water	1.20E-06	kg/kg Total Wet Weight
Magnesium	water	2.56E-05	kg/kg Total Wet Weight
Manganese	water	6.40E-07	kg/kg Total Wet Weight
Mercury	water	1.35E-07	kg/kg Total Wet Weight
Molybdenum	water	7.20E-05	kg/kg Total Wet Weight
Nickel	water	1.68E-06	kg/kg Total Wet Weight
Selenium	water	1.12E-06	kg/kg Total Wet Weight
Silicon	water	2.40E-04	kg/kg Total Wet Weight
Zinc	water	2.56E-06	kg/kg Total Wet Weight

Table A23. Material and energy requirements and corresponding Ecoinvent processes used for the modelling of the treatment of fly ashes. Values for material and energy requirements were obtained from Astrup (2008).

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
market for calcium carbonate, precipitated; GLO	-0.035	kg/kg Total Wet Weight
market group for electricity, high voltage; RER	0.013	kWh/kg Total Wet Weight
market group for diesel; RER	0.0006	kg/kg Total Wet Weight

Table A24. Emissions from treatment of fly ashes. (Astrup, 2008).

Elementary exchange	Compartment	Sub compartment	Amount	Unit	Per
Cadmium, ion	water	surface water	3.10E-09	kg	kg Total Wet Weight
Chloride	water	surface water	0.0092	kg	kg Total Wet Weight
Lead	water	surface water	3.10E-10	kg	kg Total Wet Weight
Mercury	water	surface water	6.10E-11	kg	kg Total Wet Weight
Nickel, ion	water	surface water	1.50E-09	kg	kg Total Wet Weight
Sulphate	water	surface water	0.00082	kg	kg Total Wet Weight
Thallium	water	surface water	4.10E-10	kg	kg Total Wet Weight
Zinc, ion	water	surface water	1.40E-08	kg	kg Total Wet Weight

Table A25. Bottom ashes treatment was assumed to occur in a mineral landfill.

Ecoinvent process name (v 3.4, consequential)	Amount	Unit
process-specific burdens, slag landfill; Europe without Switzerland	1	kg/kg Total Wet Weight

Appendix B. Marginal technologies

This section summarizes the technological processes that have been selected as marginal technologies for the present LCA study. “Marginal technologies” are the technologies that are assumed to be displaced by the additional functionalities provided by the functional unit. A classic example for LCAs of waste management systems is the energy produced during the treatment of waste by incineration. The energy produced represents an additional function, and electricity and heat produced are used in the energy system instead of producing primary energy from other sources.

For the present studies, marginal technologies needed to be identified for the energy recovered during incineration in Denmark and for the secondary material produced from the recycling processes. The following subsections present the processes and datasets chosen. In order to facilitate reading, the selected processes are also provided with their LCIA results according to the same references provided in Table 5 in the report. In addition, in order to provide results in the same figures, we have used the following normalization references.

Table B1. Normalization references for the impact categories in Table 5. The Normalization references are from the Prosuite project which was developed specifically for the recommended ILCD method (Laurent et al., 2013), excluded the long-term compartment. The impact category “Depletion of abiotic resources” respects ILCD recommended characterization factors

Impact Category	Acronyms	Normalization references	Units
Climate change	CC	8.10E+03	kg CO_2 eq/PE
Ozone depletion	OD	4.14E-02	kg CFC-11 eq/PE
Human toxicity, cancer effects	HTc	5.42E-05	CTUh/PE
Human toxicity, non-cancer effects	HTnc	1.10E-03	CTUh/PE
Particulate matter/Respiratory inorganics	PM	2.76E+00	kg PM2.5 eq/PE
Ionizing radiation, human health	IR	1.33E+03	kBq U235 eq./PE
Photochemical ozone formation, human health	POF	5.67E+01	kg NMVOC eq/PE
Terrestrial acidification	TA	4.96E+01	mol H+ eq/PE
Eutrophication terrestrial	TE	1.15E+02	mol N eq./PE
Eutrophication freshwater	FE	6.20E-01	kg P eq./PE
Eutrophication marine	ME	9.38E+00	kg N eq./PE
Ecotoxicity freshwater	ET	6.65E+02	CTUe/PE
Resources, depletion of abiotic resources, fossil	RDfos	6.24E+04	MJ/PE
Resources, depletion of abiotic resources (reserve base)	RD	0.0343	kg Sb eq/PE

Appendix B.1 Marginal energy technologies

Electricity

In accordance with the Danish Environmental Protection Agency and the Danish Energy Agency, the marginal energy technologies used for this project were based on the latest published project from the Danish Environmental Protection Agency, which provided marginal energy technologies for electricity and heat: TemaNord 2016:537 - Gaining benefits from discarded textiles - LCA of different treatment pathways, published by the Nordic Council of Ministers (Schmidt et al., 2016).

In this project, the long-term marginal was defined as capacity growth over a defined period (2020-2030). The marginal was provided as a mix of contributing resources, as shown in Table B2. The electricity marginal mix was then composed of electricity production from single-technology processes from the Ecoinvent v3.4 database, consequential version. The normalized results of the created process for electricity were compared to those of the electricity market, high voltage, for Denmark in Ecoinvent v3.4, consequential and found compliant (Figure B1).

Table B2. Marginal mix, electricity, TemaNord 2016:537

Resource	Percent contribution (%)	Ecoinvent v3.4 process
Biomass	49.8	Electricity production, wood, future; GLO (kWh), consequential
Gas	18.6	Electricity production, natural gas, 10MW; CH, (kWh), consequential
Wind	31.6	Electricity production, wind, <1MW turbine, onshore; DK (kWh), consequential

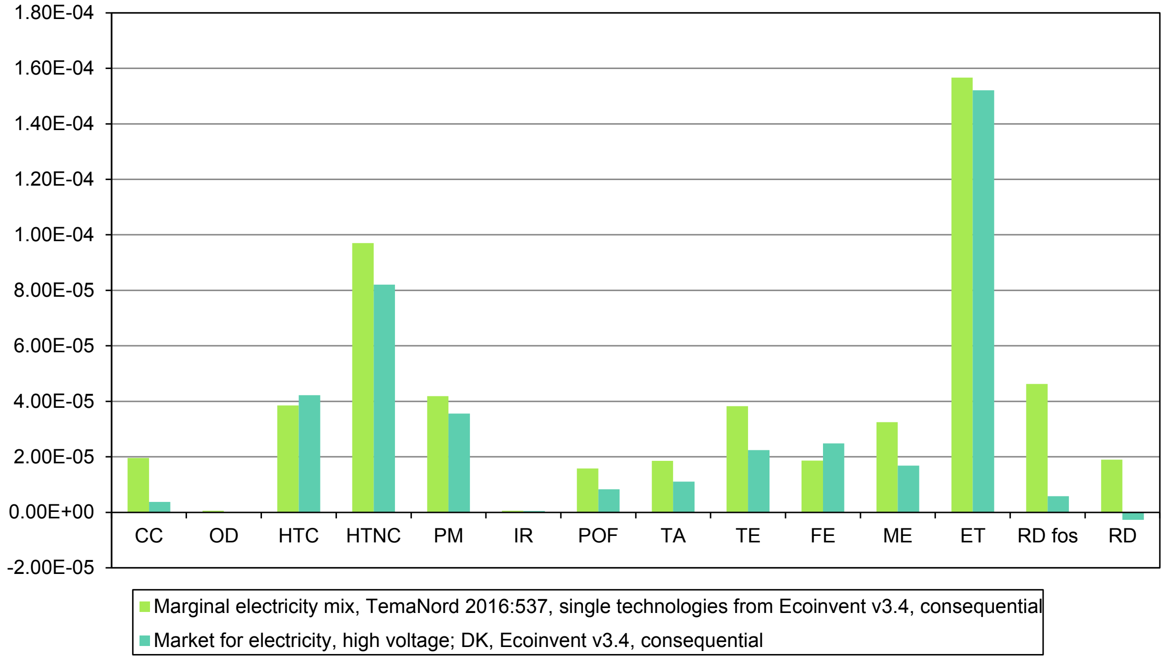

Figure B1. Marginal electricity mix normalized results, obtained from single technology dataset from Ecoinvent v3.4, consequential, according to the percent contribution identified in TemaNord 2016:537, compared to the normalized results of the market for electricity process, retrieved from Ecoinvent v3.4, consequential.

Heat

In the TemaNord 2016:537 project the marginal technology from heat was chosen based on the project Miljøprojekt 1458 (Bang Jensen et al., 2013). The contribution of resources to the marginal heat mix is provided in Table B3. In Miljøprojekt 1458 it was assumed that waste heat could not replace waste heat, therefore heat from incineration is not part of the heat marginal mix. The Ecoinvent 3.4 processes used to compose the dataset are specified in Table B3. For all processes, the selection involved finding heat production datasets from single technologies and comparing the normalized results of many single-technologies for heat production of the same type. Due to high differences between the normalized results and to the unavailability of single technologies datasets for biogas, we selected a process from the allocation at the point of substitution database instead of the consequential one. The differences in the overall normalized result are minor, due to the minor contribution of biogas. Figure B2 provides a contribution analysis of the single technologies composing the dataset.

Table B2. Marginal mix, electricity, Miljøprojekt 1458

Resource	Percent contribution (%)	Ecoinvent v3.4 process
Biomass	39	Heat production, hardwood chips from forest, at furnace 5000kW, state-of-the-art 2014; CH (MJ), consequential
Gas	26	Heat production, natural gas, at boiler modulating >100kW; Europe without Switzerland (MJ), consequential
Coal	20	Heat production, at hard coal industrial furnace 1-10MW; Europe without Switzerland (MJ), consequential
Oil	9	Heat production, heavy fuel oil, at industrial furnace 1MW; CH (MJ), consequential
Biogas	6	Heat and power co-generation, biogas, gas engine; DK (MJ), allocation at the point of substitution

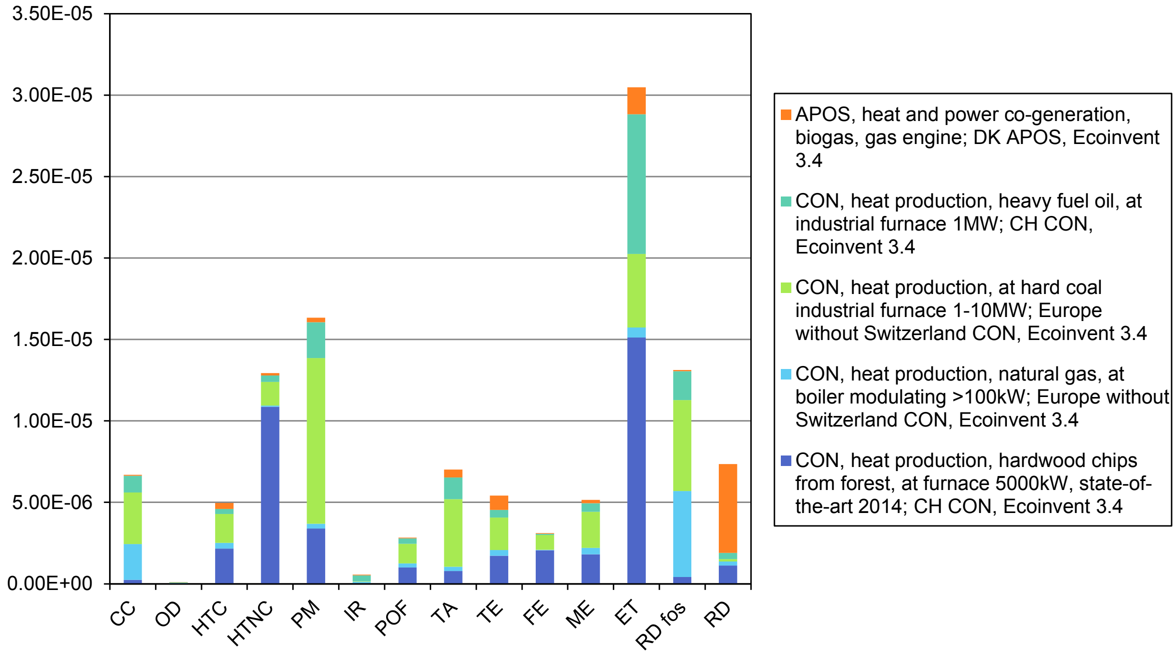

Figure B2. Normalized results and contribution analysis associated with the marginal heat technology (mix) selected for the present LCA study.

Appendix B.2 Marginal materials

The following Table B4 provides a summary of the datasets selected for the production of materials and for the recycling. The production was considered only to obtain the results presented in Section 7. All datasets were retrieved from Ecoinvent 3.4, consequential version.

Each dataset was selected after comparison of many datasets for the production and recycling of the same material. The criterion for selection of the dataset was general compliance in results with datasets for the same function, and availability of the dataset. For production, market datasets were always selected (if available), since market comprises production shares globally and average transport distances. For substitution, we selected simply the production in a specific geographical area (preferably Europe, since it is where the recycling process is assumed to occur).

Table B4. Summary of datasets used as production of materials and for the materials substituted by the secondary material produced from the recycling processes.

Material	Production	Substitution
PET	Market for polyethylene terephthalate, granulate, bottle grade; GLO (kg)	Polyethylene terephthalate production, granulate, bottle grade; RER (kg)
		Polyethylene terephthalate production, granulate, amorphous; RER (kg)
HDPE	Market for polyethylene, high density, granulate; GLO	Polyethylene production, high density, granulate; RER
Clear glass	Market for packaging glass, white; GLO	Packaging glass production, white; RER w/o CH+DE
Green glass	Market for packaging glass, green; GLO	Packaging glass production, green; RER w/o CH+DE
Brown glass	Market for packaging glass, brown; GLO	Packaging glass production, brown; RER w/o CH+DE
Aluminium	Market for aluminium, primary, ingot; IAI Area, EU27 & EFTA	Aluminium production, primary, ingot; IAI Area, EU27 & EFTA
Composite	Market for liquid packaging board container; GLO	Linerboard production, kraftliner; RER

Appendix C. **Additional results**

Additional results for section 7.4

Results for Juice products – Ready to drink

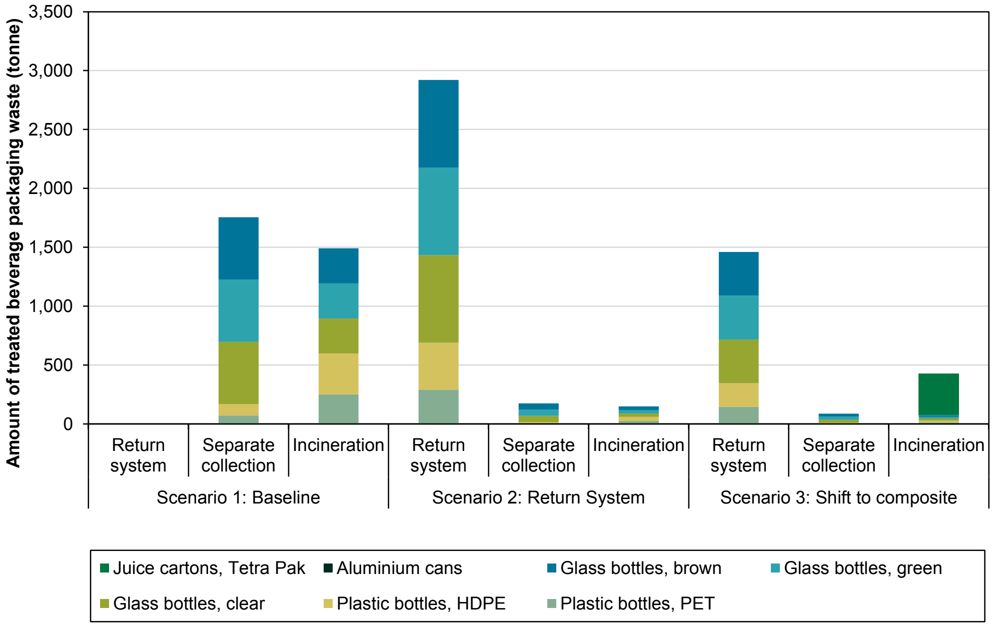

Figure C1. The amounts for Scenario 1 the current system with 25 % separate collection of plastic, 50 % separate collection of metals, and 75 % separate collection of glass. for **The graph shows Juice ready to drink.**

Table C1. Comparison of Scenario 1 (Baseline), Scenario 2 (return system), and Scenario 3 (50 % shift to composite materials, and 50 % return system). Values are given as person equivalents (PE) for Juice ready to drink.

Impact category	Scenario 1 (PE)	Scenario 2 (PE)	Scenario 3 (PE)
Climate change	39	-305	-169
Ozone depletion	-3	-2	-2
Human toxicity, cancer effects	-481	-1038	-634
Human toxicity, non-cancer effects	-449	-263	-239
Particulate matter/Respiratory inorganics	-641	-1019	-608
Ionizing radiation, human health	-20	-22	-16
Photochemical ozone formation, human health	-71	-150	-90
Terrestrial acidification	-199	-257	-170
Eutrophication terrestrial	-175	-238	-152
Eutrophication freshwater	-213	-402	-227
Eutrophication marine	-115	-189	-119
Ecotoxicity freshwater	-793	-2506	-1541

Resources, depletion of abiotic resources, fossil	-513	-1168	-671
Resources, depletion of abiotic resources, elements	-1653	-4663	-2430

Table C2. Comparison of changes from Scenario 1 (Baseline) to Scenario 2 (return system) and Scenario 3 (50 % shift to composite materials, and 50 % return system) respectively. A positive value is where Scenario 1 has the lowest comparative impact, and a negative value means that Scenario 2 and 3 leads to lower comparative impacts. Values are for Juice ready to drink.

Impact category	Unit	S1:S2	S1:S3
Climate change	%	-883	-534
Ozone depletion	%	34	43
Human toxicity, cancer effects	%	-116	-32
Human toxicity, non-cancer effects	%	41	47
Particulate matter/Respiratory inorganics	%	-59	5
Ionizing radiation, human health	%	-8	19
Photochemical ozone formation, human health	%	-111	-26
Terrestrial acidification	%	-29	15
Eutrophication terrestrial	%	-36	13
Eutrophication freshwater	%	-89	-7
Eutrophication marine	%	-65	-3
Ecotoxicity freshwater	%	-216	-94
Resources, depletion of abiotic resources, fossil	%	-127	-31
Resources, depletion of abiotic resources, elements	%	-182	-47

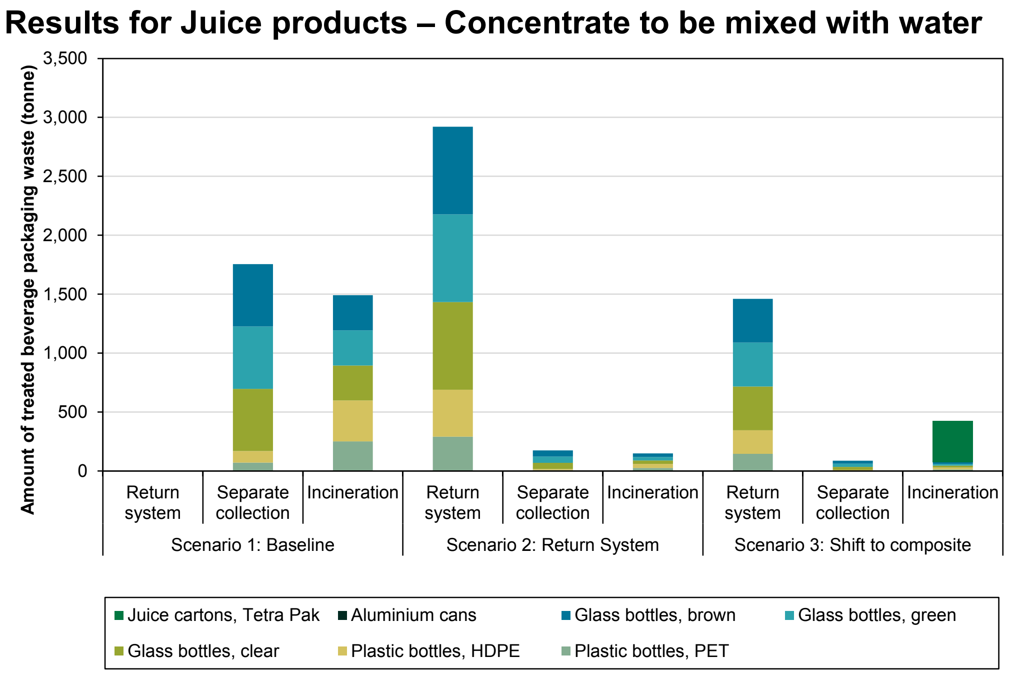

Figure C2. The amounts for Scenario 1 the current system with 25 % separate collection of plastic, 50 % separate collection of metals, and 75 % separate collection of glass. for **The graph shows Juice - concentrated to be mixed with water products.**

Table C3. Comparison of Scenario 1 (Baseline), Scenario 2 (return system), and Scenario 3 (50 % shift to composite materials, and 50 % return system). Values are given as person equivalents (PE) for Juice - concentrated to be mixed with water products.

Impact category	Scenario 1 (PE)	Scenario 2 (PE)	Scenario 3 (PE)
Climate change	24	-277	-152
Ozone depletion	-3	-2	-2
Human toxicity, cancer effects	-344	-808	-501
Human toxicity, non-cancer effects	-360	-237	-209
Particulate matter/Respiratory inorganics	-605	-1095	-630
Ionizing radiation, human health	-15	-18	-14
Photochemical ozone formation, human health	-43	-120	-72
Terrestrial acidification	-151	-225	-147
Eutrophication terrestrial	-133	-232	-144
Eutrophication freshwater	-213	-427	-235
Eutrophication marine	-67	-158	-99
Ecotoxicity freshwater	-652	-2344	-1413
Resources, depletion of abiotic resources, fossil	-409	-971	-559
Resources, depletion of abiotic resources, elements	-2249	-5379	-2772

Table C4. Comparison of changes from Scenario 1 (Baseline) to Scenario 2 (return system) and Scenario 3 (50 % shift to composite materials, and 50 % return system) respectively. A positive value is where Scenario 1 has the lowest comparative impact, and a negative value means that Scenario 2 and 3 leads to lower comparative impacts. Values are for Juice - concentrated to be mixed with water products.

Impact category	Unit	S1:S2	S1:S3
Climate change	%	-1268	- 743
Ozone depletion	%	11	32
Human toxicity, cancer effects	%	-135	-45
Human toxicity, non-cancer effects	%	34	42
Particulate matter/Respiratory inorganics	%	-81	-4
Ionizing radiation, human health	%	-23	7
Photochemical ozone formation, human health	%	-178	-67
Terrestrial acidification	%	-50	2
Eutrophication terrestrial	%	-75	-8
Eutrophication freshwater	%	-100	-10
Eutrophication marine	%	-137	-49
Ecotoxicity freshwater	%	-259	-117
Resources, depletion of abiotic resources, fossil	%	-137	-37
Resources, depletion of abiotic resources, elements	%	-139	-23

Results for Milk products

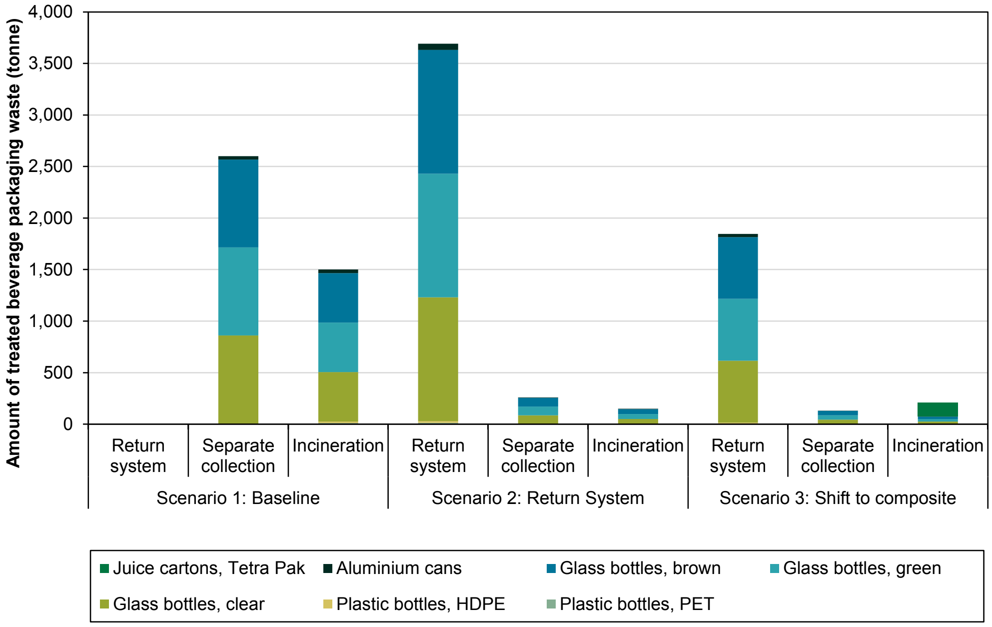

Figure C3. The amounts for Scenario 1 the current system with 25 % separate collection of plastic, 50 % separate collection of metals, and 75 % separate collection of glass. The graph shows milk products.

Table C5. Comparison of Scenario 1 (Baseline), Scenario 2 (return system), and Scenario 3 (50 % shift to composite materials, and 50 % return system). Values are given as person equivalents (PE) for milk products.

Impact category	Scenario 1 (PE)	Scenario 2 (PE)	Scenario 3 (PE)
Climate change	-90	-263	-137
Ozone depletion	-2	-4	-2
Human toxicity, cancer effects	-825	-1689	-881
Human toxicity, non-cancer effects	-84	-306	-187
Particulate matter/Respiratory inorganics	-534	-1326	-695
Ionizing radiation, human health	-25	-62	-33
Photochemical ozone formation, human health	16	-63	-36
Terrestrial acidification	-48	-212	-119
Eutrophication terrestrial	-22	-234	-128
Eutrophication freshwater	-222	-504	-261
Eutrophication marine	47	-105	-60
Ecotoxicity freshwater	-1152	-3328	-1756
Resources, depletion of abiotic resources, fossil	-175	-474	-265
Resources, depletion of abiotic resources, elements	-2346	-6475	-3269

Table C6. Comparison of changes from Scenario 1 (Baseline) to Scenario 2 (return system) and Scenario 3 (50 % shift to composite materials, and 50 % return system) respectively. A positive value is where Scenario 1 has the lowest comparative impact, and a negative value means that Scenario 2 and 3 leads to lower comparative impacts. Values are for milk products.

Impact category	Unit	S1:S2	S1:S3
Climate change	%	-192	-52
Ozone depletion	%	-182	-56
Human toxicity, cancer effects	%	-105	-7
Human toxicity, non-cancer effects	%	-263	-122
Particulate matter/Respiratory inorganics	%	-148	-30
Ionizing radiation, human health	%	-145	-29
Photochemical ozone formation, human health	%	502	330
Terrestrial acidification	%	-337	-146
Eutrophication terrestrial	%	-948	-470
Eutrophication freshwater	%	-127	-17
Eutrophication marine	%	321	227
Ecotoxicity freshwater	%	-189	-52
Resources, depletion of abiotic resources, fossil	%	-171	-51
Resources, depletion of abiotic resources, elements	%	-176	-39

Additional results for section 6

HDPE with higher recycling efficiency

In Table C7 are shown values if we assume a recycling efficiency of 99% for the HDPE recycling, which is the same high value as for high quality recycling of PET. Overall the results show that HDPE only is better than incineration in 4 out of 14 categories, which are similar to the normal results.

Table C7. Characterized results for HDPE for each impact categories assessed. Results are expressed as characterized impacts per reference flow (1000 kg of beverage packaging waste, mono material). The first three columns are the regular results. "RS – High" is with the higher efficiency of recycling.

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	kg CO_2 eq	kg CFC11 eq	CTUh	CTUh	kgPM2.5 eq	kBq U235 eq	kg NMVOC	mol H+ eq	mol N eq	kg P eq	kg N eq	CTUe	MJ	kg Sb eq
RS	-1.40E+03	3.66E-05	-1.31E-05	-2.42E-05	-8.14E-01	1.64E+01	-7.70E+00	-7.50E+00	-1.28E+01	-1.53E-02	-1.16E+00	-3.50E+02	-6.15E+04	2.45E-03
SC	-4.64E+02	7.21E-06	-1.08E-05	-1.50E-04	-7.58E-01	5.33E+00	-5.65E+00	-7.65E+00	-1.28E+01	-5.84E-02	-1.04E+00	1.46E+02	-4.51E+04	-1.86E-04
INC	9.10E+02	-1.38E-04	-1.13E-05	-5.53E-04	-1.29E+00	-2.11E+01	-4.66E+00	-9.94E+00	-2.20E+01	-7.06E-02	-1.43E+00	-7.08E+02	-2.49E+04	-1.53E-02
RS - High	-1.63E+03	3.78E-05	-1.31E-05	1.17E-05	-8.05E-01	1.95E+01	-8.01E+00	-6.98E+00	-1.24E+01	8.56E-03	-1.14E+00	-6.23E+02	-6.35E+04	2.60E-03

Marginal electricity is 100% wind power

In Table C8 are shown values when assuming that marginal eleciricity is 100% wind power. The only change is that the returns system for PET and HDPE are better in one more category in comparison to the results with the mixed marginal electricity.

Table C8. Characterized results for all materials for each impact categories assessed. Results are expressed as characterized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	kg CO_2 eq	kg CFC11 eq	CTUh	CTUh	kgPM2.5 eq	kBq U235 eq	kg NMVOC	mol H+ eq	mol N eq	kg P eq	kg N eq	CTUe	MJ	kg Sb eq
PET, RS	-2.68E+03	-6.56E-05	-4.92E-05	-2.87E-04	-2.01E+00	-2.20E+01	-7.86E+00	-1.10E+01	-2.14E+01	-2.79E-01	-1.89E+00	-1.70E+03	-7.49E+04	-1.69E-01
PET, SC	-5.52E+02	-2.66E-05	-2.20E-05	-2.06E-04	-1.04E+00	-1.23E+01	-4.06E+00	-7.60E+00	-1.24E+01	-1.52E-01	-1.00E+00	2.85E+03	-4.05E+04	-5.96E-02
PET, INC	1.19E+03	-9.49E-05	-1.14E-05	-3.47E-04	-1.09E+00	-1.99E+01	-2.95E+00	-8.17E+00	-1.34E+01	-5.24E-02	-8.43E-01	-5.59E+02	-1.96E+04	-1.49E-02
HDPE, RS	-1.40E+03	3.67E-05	-1.31E-05	-2.39E-05	-8.14E-01	1.64E+01	-7.70E+00	-7.49E+00	-1.28E+01	-1.53E-02	-1.16E+00	-3.50E+02	-6.15E+04	2.45E-03
HDPE, SC	-4.24E+02	1.32E-05	-1.08E-05	-1.21E-04	-7.31E-01	5.49E+00	-5.41E+00	-7.40E+00	-1.16E+01	-5.58E-02	-9.54E-01	1.67E+02	-4.44E+04	-1.37E-04
HDPE, INC	1.19E+03	-9.49E-05	-1.14E-05	-3.47E-04	-1.09E+00	-1.99E+01	-2.95E+00	-8.17E+00	-1.34E+01	-5.24E-02	-8.43E-01	-5.59E+02	-1.96E+04	-1.49E-02
Glass clear, RS	-3.98E+02	-3.35E-05	-9.87E-06	-5.46E-05	-8.56E-01	-9.58E+00	-4.86E-01	-1.79E+00	-5.93E+00	-7.16E-02	-1.67E-01	-3.79E+02	-4.93E+03	-5.70E-02
Glass clear, SC	-1.90E+02	-1.69E-05	-6.11E-06	-2.38E-05	-4.94E-01	-5.24E+00	1.75E-01	-5.67E-01	-2.19E+00	-4.57E-02	4.72E-02	-1.74E+02	-2.40E+03	-3.81E-02
Glass clear, INC	6.63E+01	8.85E-06	2.66E-07	1.03E-05	6.40E-02	2.52E+00	1.11E+00	9.44E-01	4.44E+00	1.83E-03	4.01E-01	7.04E+01	1.07E+03	-2.68E-03
Glass green, RS	-4.52E+02	-3.93E-05	-1.04E-05	-6.26E-05	-9.04E-01	-1.10E+01	-6.68E-01	-2.11E+00	-6.80E+00	-7.73E-02	-2.23E-01	-4.36E+02	-5.94E+03	-5.87E-02
Glass green, SC	-2.31E+02	-2.13E-05	-6.34E-06	-3.17E-05	-5.29E-01	-6.22E+00	3.03E-02	-8.12E-01	-2.88E+00	-4.98E-02	2.04E-03	-2.13E+02	-3.15E+03	-3.93E-02
Glass green, INC	5.66E+01	8.18E-06	1.12E-06	6.64E-06	5.59E-02	2.50E+00	1.08E+00	8.77E-01	4.26E+00	1.35E-03	3.90E-01	7.97E+01	9.26E+02	-3.13E-03
Glass brown, RS	-3.90E+02	-3.21E-05	-9.84E-06	-5.43E-05	-8.55E-01	-9.13E+00	-4.59E-01	-1.78E+00	-5.89E+00	-7.19E-02	-1.61E-01	-3.69E+02	-4.81E+03	-5.72E-02
Glass brown, SC	-1.86E+02	-1.60E-05	-6.07E-06	-2.40E-05	-4.94E-01	-4.94E+00	1.89E-01	-5.67E-01	-2.18E+00	-4.60E-02	5.06E-02	-1.67E+02	-2.34E+03	-3.82E-02
Glass brown, INC	5.80E+01	8.24E-06	3.40E-07	6.98E-06	5.71E-02	2.50E+00	1.08E+00	8.87E-01	4.28E+00	1.42E-03	3.91E-01	7.15E+01	9.45E+02	-3.04E-03

Aluminium, RS	-8.46E+03	-7.66E-04	1.97E+00	-1.95E-03	-3.52E-01	-7.11E+02	-9.92E+00	5.74E+01	-6.36E+01	-5.01E-01	-5.33E+00	-2.95E+03	-1.27E+05	-7.27E-02
Aluminium, SC	-7.05E+03	-5.72E-04	1.43E+00	-1.30E-03	-1.26E+00	-5.11E+02	-9.51E+00	3.64E+01	-5.28E+01	-3.77E-01	-4.45E+00	-2.61E+03	-1.05E+05	7.83E-01
Aluminium, INC	-2.80E+03	-2.28E-04	-2.54E-04	4.97E-04	-1.90E+00	-1.81E+02	-6.45E+00	-1.09E+01	-1.10E+01	-1.42E-01	-8.43E-01	-3.31E+03	-3.94E+04	-4.62E-02
Composite, RS	-3.51E+02	-6.43E-05	-2.98E-06	-1.48E-04	4.73E-01	-1.92E+01	-1.13E+00	-9.71E-01	-9.49E-01	-3.94E-02	-3.52E-01	-2.86E+01	-4.48E+03	-2.30E-01
Composite, SC	-1.78E+02	-5.48E-05	-2.85E-06	-1.37E-04	2.40E-01	-1.65E+01	-9.20E-01	-1.29E+00	-1.28E+00	-3.48E-02	-2.66E-01	2.08E+02	-4.88E+03	-3.06E-01
Composite, INC	-1.86E+02	-5.18E-05	-1.50E-05	-1.86E-04	-5.59E-01	-1.71E+01	-1.16E+00	-4.08E+00	-4.92E+00	-3.02E-02	-2.61E-01	-3.86E+02	-1.05E+04	-7.88E-03

Marginal heat is 100% biomass

In Table C8 are shown values when assuming that marginal elecricity is 100% wind power. In this case there is a slight improvement, as the returns system for PET and HDPE are now better in one more category in comparison to the results with the mixed marginal heat.

Table C9. Characterized results for all materials for each impact categories assessed. Results are expressed as characterized impacts per reference flow (1000 kg of beverage packaging waste, mono material).

Beverage packaging material	CC	OD	HTC	HTNC	PM	IR	POF	TA	TE	FE	ME	ET	RD fos	RD
	kg CO_2 eq	kg CFC11 eq	CTUh	CTUh	kgPM2.5 eq	kBq U235 eq	kg NMVOC	mol H+ eq	mol N eq	kg P eq	kg N eq	CTUe	MJ	kg Sb eq
PET, RS	-2.68E+03	-6.55E-05	-4.92E-05	-2.88E-04	-2.01E+00	-2.20E+01	-7.86E+00	-1.10E+01	-2.14E+01	-2.79E-01	-1.89E+00	-1.70E+03	-7.49E+04	-1.69E-01
PET, SC	-4.10E+02	-2.02E-05	-2.20E-05	-2.92E-04	-9.87E-01	-9.89E+00	-4.23E+00	-6.87E+00	-1.28E+01	-1.59E-01	-1.06E+00	2.82E+03	-3.85E+04	-5.78E-02
PET, INC	2.12E+03	-5.51E-05	-1.11E-05	-9.35E-04	-7.55E-01	-3.68E+00	-4.21E+00	-3.40E+00	-1.67E+01	-9.92E-02	-1.26E+00	-8.00E+02	-6.72E+03	-3.18E-03
HDPE, RS	-1.40E+03	3.68E-05	-1.31E-05	-2.48E-05	-8.13E-01	1.64E+01	-7.70E+00	-7.49E+00	-1.28E+01	-1.53E-02	-1.16E+00	-3.50E+02	-6.15E+04	2.47E-03
HDPE, SC	-2.82E+02	1.97E-05	-1.08E-05	-2.08E-04	-6.78E-01	7.95E+00	-5.58E+00	-6.67E+00	-1.20E+01	-6.27E-02	-1.01E+00	1.32E+02	-4.24E+04	1.63E-03
HDPE, INC	2.12E+03	-5.51E-05	-1.11E-05	-9.35E-04	-7.55E-01	-3.68E+00	-4.21E+00	-3.40E+00	-1.67E+01	-9.92E-02	-1.26E+00	-8.00E+02	-6.72E+03	-3.18E-03
Glass clear, RS	-3.97E+02	-3.34E-05	-9.87E-06	-5.48E-05	-8.56E-01	-9.58E+00	-4.86E-01	-1.78E+00	-5.92E+00	-7.16E-02	-1.67E-01	-3.79E+02	-4.92E+03	-5.70E-02
Glass clear, SC	-1.91E+02	-1.70E-05	-6.11E-06	-2.34E-05	-4.95E-01	-5.26E+00	1.74E-01	-5.73E-01	-2.19E+00	-4.57E-02	4.70E-02	-1.74E+02	-2.42E+03	-3.81E-02
Glass clear, INC	5.60E+01	8.14E-06	2.64E-07	1.36E-05	5.95E-02	2.37E+00	1.11E+00	8.88E-01	4.39E+00	2.08E-03	4.00E-01	7.12E+01	9.16E+02	-2.79E-03
Glass green, RS	-4.52E+02	-3.92E-05	-1.04E-05	-6.28E-05	-9.04E-01	-1.10E+01	-6.68E-01	-2.11E+00	-6.80E+00	-7.73E-02	-2.24E-01	-4.36E+02	-5.93E+03	-5.87E-02
Glass green, SC	-2.28E+02	-2.08E-05	-6.34E-06	-2.97E-05	-5.27E-01	-6.21E+00	4.75E-02	-7.94E-01	-2.79E+00	-4.96E-02	7.96E-03	-2.11E+02	-3.10E+03	-3.93E-02
Glass green, INC	5.46E+01	8.10E-06	1.12E-06	7.88E-06	5.52E-02	2.46E+00	1.08E+00	8.67E-01	4.27E+00	1.45E-03	3.91E-01	8.02E+01	8.99E+02	-3.15E-03
Glass brown, RS	8.33E+01	-3.21E-05	-9.84E-06	-5.45E-05	-8.55E-01	-9.12E+00	-4.59E-01	-1.77E+00	-5.89E+00	-7.19E-02	-1.60E-01	-3.69E+02	-4.80E+03	-5.72E-02
Glass brown, SC	1.56E+02	-1.60E-05	-6.07E-06	-2.40E-05	-4.94E-01	-4.94E+00	1.89E-01	-5.68E-01	-2.18E+00	-4.60E-02	5.05E-02	-1.67E+02	-2.34E+03	-3.82E-02
Glass brown, INC	5.49E+01	8.11E-06	3.39E-07	8.93E-06	5.60E-02	2.45E+00	1.09E+00	8.71E-01	4.29E+00	1.57E-03	3.92E-01	7.23E+01	9.02E+02	-3.08E-03

Aluminium, RS	-8.46E+03	-7.66E-04	1.97E+00	-1.95E-03	-3.52E-01	-7.11E+02	-9.92E+00	5.74E+01	-6.36E+01	-5.01E-01	-5.33E+00	-2.95E+03	-1.27E+05	-7.27E-02
Aluminium, SC	-7.05E+03	-5.72E-04	1.43E+00	-1.29E-03	-1.26E+00	-5.11E+02	-9.50E+00	3.64E+01	-5.27E+01	-3.77E-01	-4.44E+00	-2.61E+03	-1.04E+05	7.83E-01
Aluminium, INC	-2.80E+03	-2.28E-04	-2.54E-04	5.00E-04	-1.90E+00	-1.81E+02	-6.44E+00	-1.10E+01	-1.10E+01	-1.42E-01	-8.41E-01	-3.31E+03	-3.95E+04	-4.63E-02
Composite, RS	-3.50E+02	-6.43E-05	-2.98E-06	-1.49E-04	4.73E-01	-1.92E+01	-1.14E+00	-9.67E-01	-9.53E-01	-3.95E-02	-3.53E-01	-2.90E+01	-4.46E+03	-2.30E-01
Composite, SC	-1.08E+02	-5.18E-05	-3.19E-06	-1.75E-04	2.66E-01	-1.56E+01	-9.77E-01	-9.18E-01	-1.32E+00	-3.82E-02	-2.84E-01	1.90E+02	-3.93E+03	-3.06E-01
Composite, INC	2.54E+02	-3.29E-05	-1.48E-05	-4.65E-04	-4.00E-01	-9.39E+00	-1.76E+00	-1.82E+00	-6.44E+00	-5.24E-02	-4.60E-01	-5.00E+02	-4.42E+03	-2.32E-03

Appendix D. Note from Dansk Retursystem A/S

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9 Appendix E. Critical review

10 Generelle kommentarer

Generelle aspekter	Kommentarer fra COWI, første runde Linjenummer refererer til rapport, version marts 2018	Svar på kommentarer fra DTU Miljø Linjenummer refererer til rapport, version marts 2018	Kommentarer fra COWI, anden runde Linjenummer refererer til rapport, version maj 2018	Svar på kommentarer fra DTU Miljø Linjenummer refererer til rapport, version maj 2018
Metoderne anvendt er i overensstemmelse med denne internationale standard	Ja, i vid udstrækning.			
Metoderne er videnskabeligt og teknisk gyldige.	Ja			
Anvendte data er hensigtsmæssige og fornuftige	Generelt ja			
Vurderingsrapporten er gennemskuelig og konsekvent	Afsnit 2 er forvirrende: Det fremgår ikke klart af afsnittet, at denne rapport fokuserer på miljøeffekten af at inkludere yderligere emballager i pantsystemet. Og præcist hvilke emballager dette er (materialer og drikkevarer). Dette kunne tilføjes til sidste sætning i første afsnit (linje 449-450).	The whole chapter has been rewritten	Generelt OK (mere overskueligt afsnit), men kommentarer til det nye afsnit: Linje 597 – er dette kun aluminium? Linje 600: Uklar sætning. Hvad er "these types"? Linje 602 – hvad består cardboard containers af (cardboard og plastic foil?) – Det er generelt uklart hvorfor cardboard ikke er med i beregningerne (men nævnes mange gange i flere afsnit), imens composite (cardboard/plastic/aluminium) er med i analysen.	Ændret til ” Aluminium beverage cans” Omskrevet sætning Cardboard containers fjernet, da vi kun har modelleret composite der er de mest normale. De er fjernet i hele rapporten
	› Denne sætning (linje 449-450) er i øvrigt uklar, idet man her ikke får	› More details added as written	OK	

	forklaret, hvad "the new material" er.	above, and add carbonated in front of alcoholic drinks.		
	› Linje 461-464: Dette er carbonated softdrinks, alcoholic drinks and bottled water i andre emballager. Er det disse vi ser på i projektet?	This is not a part of the Nielsen data, and can therefore not be included here.	OK	
	› Og hvordan hænger det sammen med table 1 (linje 479-500), som opgør emballager for mælk og juice i plast, glas og metal emballager? Burde man også vise komposit emballagerne for juice og mælk i denne tabel?	Totals has been added. Furthermore we have added data for Juice and Milk seperatly.	OK	
	› Table 1 og 2: Det vil gøre det mere overskueligt, hvis man tilføjer totaler for hvert år.	We have updated the tables so its clearer what the jump is due to. It can be seen it is mainly an increase in glass for milk products, where it can be traced to a number of specific products that must have had a marketing push with an increased demand to follow.	OK	
	› Table 1: Kommenter gerne på udviklingen i antal solgte (der er nogle voldsomme "hop").		Ikke besvaret. Har DTU antaget "typiske volumener" for de forskellige materialer?	Lettere omformulerete så det er klart det er baseret på Nielsen data. “The values in Table 1 were converted to total weight by combining information on the

				volume for the individual products in the Nielsen data, with an average weight per cl for the four packaging types”
	› Uklart hvordan der omregnes fra table 1 til table 2, da der ikke er opgjort volumen i table 1.	Rewritten as suggested • *HDPE plastic: 0.62 g per cl. content* • *PET plastic:0.45 g per cl. content* • *Glass:7.9 g per cl. content* • *Aluminium: 0.69 g per cl. content* • *Tetra Pak: 0.40 g per cl. Content*		
	› Linje 490-494: Noget knudret skrevet. Forslag: HDPE plastic: 0.62 g/cl content.			
	› Linje 474: "drinking packaging in use in the danish retail sector". Er det udenfor pantsystemet eller totalt? Og er det det, som er inkluderet i projektet?	Reworded		
			Linje 636 – hvorfor er der vægt på tetrapak? Forklar at det anvendes senere. OK Savner en sammenligning af	Linje tilføjet: ” The weight for composite packaging is included to allow for comparison in Section 7, but is not used further in this section. “

			data under Table 2 og 3 – Kan potentialet stadig forventes højere end Nielsen's data? Herudover kommentater til nye Miljøstyrelsesdata: der mangler enhed i Table 3 – er det i tons/år?. Det er uklart om tallene dækker over alene emballager samt om tallene dækker både husholdnings- og erhvervsaffald? Det står uklart her, hvad tallene skal bruges til? - forklar. Linje 678 – 684: kommer meget pludselig og hører mere med under begrænsninger?	
			Kommentarer til nyt Executive summery: Må generelt gerne være mere skarpt, let forståeligt og mindre teknisk. Dette afsnit skal kunne læses separat og give et overblik og forståelse af rapportens formål, metode og hoved-konklusioner. F.eks. linje 142-164: Formlerne for beregning af tab i genanvendelseskæden er ikke meget væsentligt for at beskrive de store linjer i projektet. Referer gerne her til andre afsnit i rapporten (for at kunne gøre det mere overordnet dette afsnit). Uklare afsnit: linje 93-99 og linje 202-206.	Vi har bibeholdt længden på dette, da vores erfaring er dette ofte er det eneste der læses. Vi har opdateret begge de to sumaries og ændret i forhold til de foreslåede ændringer

			Det engelske og danske er ikke ens – eks. står der forskellige ting linje 105 og linje 263-4. Det er uklart her, at projektet kun omhandler recyclable og ikke refillable emballager. Forklar begreber før de bruges. Eks. er monomaterialer ikke forklaret før FU. Svært at forstå illustrative scenarier. Det er vigtigt at få alle gode pointer med i summary, f.eks. at SC kommer på andenplads i mange tilfælde, at høj kvalitet i genanvendelse er vigtig og at hvis en stor del af emballagerne overgår til composite, tabes en stor del af miljøgevinsten ved udvidelse af pantsystemet.	
Småting	Linje 360+361: Reused i stedet for recycled?	Changed "Empty refillable packaging must be returned to stores, where they are ~~recycled~~ reused by refilling and, when a refillable packaging can no longer be ~~recycled~~ reused, the materials are recovered."	OK	
	Linje 453: Indsæt "carbonated" efter "and", så man ikke tror, at det inkluderer vin og spiritus mv. (ikke alle læsere er nødvendigvis danskere).	Corrected. "Dansk Retursystem is currently handling packaging of car-	OK	

		bonated soft drinks and *carbonated* alcoholic drinks as well as bottled water which is sold in Denmark."		
	Linje 501: The total value …is 6590"??? Hvad er enheden? Og tallet stemmer ikke med summen af 2016? Værdien omregnes til 13 % af DRS' mængder. Dette er forvirrende skrevet. Omformuleres.	Corrected and expanded	OK Skriv gerne hvad informationen om at mængden udgør 21% af DRS nuværende mængde skal bruges til. Eller slet det, da det uddybes til sidst.	Fjernet som foreslået.
	Linje 586-588: Her kunne specificeres, at mængden af recovered aluminium bestemmes af systemet, herunder A og B.	Added. A full explanation on how A and B works has been added. "	OK	
	Linje 591: Genanvendelsesprocessen mangler.	Corrected.We have added "recycling" in Europe, since it occurs abroad for almost all waste beverage packaging types. We specified that the whole management process for glass beverage packaging waste occurs in Denmark.	OK	
	Linje 593: Her mangler genanvendelsesprocessen. "final disposal of rejects". Her bør tilføjes "from sorting facilities not located in Denmark".	Corrected	OK	
	Linje 653: Her bør stå "metal (aluminium)"	Corrected.	OK	

	for at følge logikken.	"The beverage packaging materials selected were the following: plastic (PET and HDPE), glass (clear, green and brown), *metal (aluminium)*, composite (as juice cartons, Tetra Pak)."		
			Linje 667-668: Det er ikke tydeligt, hvordan man ser sammenhængen imellem fee based system (og hvad er det?) og normal collection system ud fra Table 3?	Delkapitel omskrevet til at være mere klart.
	Linje 673: Specificer, at vi kun ser på den genanvendelige (og ikke genpåfyldelige) del af håndteringen hos Dansk Retursystem.	Corrected *"The beverage packaging waste is collected at Danish supermarkets by the return system. As described in section 2 this assessment only considers packaging material that is collected for recycling, the collected beverage packaging is therefore transported to a sorting facility in Denmark, where the waste undergoes a fine sorting process that separates 97.7 % high quality material and 2.2 % material with a lower*	OK	

		quality"		
	Linje 691 og 696: Her bør stå "to" i stedet for "in"	Corrected.	OK	
	Linje 677: Specificer at rejekt fra sortering hos Dansk Retursystem udgør 0,1% af input mængden.	Specified. "The beverage packaging waste is collected at Danish supermarkets by the return system. The beverage packaging is transported to a sorting facility in Denmark, where the waste undergoes a fine sorting process that separates 97.7 % high quality material and 2.2 % material with a lower quality. *Rejects from sorting at Dansk Retursystem constitute 0.1% of the input amount."*	OK	
	Linje 735-737: Forklar hvad sker der med resten af materialet (100-81)? Erstatter det genanvendelige materialer eller ingenting?	Added. The market response indicates the extent of the material substitution in the market obtainable from the recycled material. For example, if B is 100 %, all the recovered material can be considered as effectively avoiding production of material from virgin resources.	OK	

		If B is lower than 100 % (for example 81 % in the case of PET and HDPE), it means that the recovered material still needs an additional amount of virgin material in order to reach the same functional properties. As far as a mass balance is concerned, this does not mean that part of the recovered material goes for waste (for example 19 % for PET and HDPE). All material recovered after the technological efficiency (A) is recycled, but 19 % of it does not provide substitution of virgin material, since a corresponding amount of virgin material has to be added to reach the same functional properties (Miljøstyrelsen, 2006)		
	Linje 747: Egentlig er det vel "Amount substituted" og ikke "Amount recycled"? Her er "Purity" og "Sorting" nye termer. Der kan med fordel tilføjes ordforklaring.	Added.	Der står stadig "Total recycled material" i eq. 4 – der bør stå substituteted når det inkluderer B (linje 967). Amount recycled ekskluderer B. Vær helt skarp på hvad forskellen på A og Sorting er –	Rettet Omformuleret til " The sorting efficiency represents the amounts after losses

			det er fortsat lidt uklart. Forklar evt. med bullets de enkelte termer.	from sorting of the material, prior to the actual recycling process where there can be further losses which is covered by the A factor."
	Linje 764: Det er stadig uklart hvilke emballager der er med. Derfor uddyb sætningen ala: "Current practice for handling of packaging material for milk and juice (PET, HDPE, aluminium and glass)".	Reworded full chapter	OK	
	Linje 765: Kilde til indsamlingseffektiviteter? Virker umiddelbart lidt høje for plast og metal ift. at der er tale om eksisterende gennemsnit i DK. For henteordninger er i en nyligt afsluttet rapport for MST anvendt 30% for plast og 60% for metal. Og disse ordninger findes endnu ikke i alle kommuner. Men det kommer an på om vi taler 2017/18 eller 2020-2030. Tidsperspektivet gælder også for scenarie 3, da ingen danske kommuner i dag genanvender kompositmateriale/tetra pak. I dag (2017/18) vil alt komposit materiale gå til forbrænding, -i 2020-2030 kan man diskutere, om indsamlingseffektiviteten vil være 50 %?	Changed the composite to 100 % incienration. Added the following sentence: The whole chapter are now just examples, and this has been made clearer.	Dette er nu i section 7.4.1. Scenario 1: Det er nye indsamlingseffektiviteter sammenlignet med sidst, -stadig ingen referencer? Det virker højt med indsamling af 72% aluminiumsemballage – før var det 50%. I linje 1901 refereres der til kapitel 2 ang. "current efficiencies in the waste management system", men I kapitel 2 findes der kun hvor store emballagemængder der kommer på markedet, som kunne inkluderes I pantsystemet? Scenarie 3: 7.4.1, Line 1938: Forklar, at komposit emballage ikke er en del af RS i de illustrative scenarier. Det er stadig ikke helt klart og noget forvirrende.	Det er gjort klart hvor indsamlingseffektivteteterne kommer fra. I 2.3 er det gjort ydereligere klart at de 72% inkluderer materiale allerede udsorteret til Dansk Retursystem, og den reelle lavere effektivtet uden retursystemet er også vist. Dette var i Tabel 3. Tabellen er blevet gjort mere klart. Tilføjet
	Linje 771-775: Det er uklart hvilke mæng-	We have rewritten the	OK	

	der flyttes (50 % af hvad?). Kan det specificeres nærmere, at det er 50 % af det antal drikkevare-enheder (eller 50 % af vægt?), der i dag sælges i emballagetyper, der ville indgå i pantsystemet, hvis mælk og juice var omfattet af pantsystemet? Hvis det altså er rigtigt forstået.	whole chapter. Furthermore chapters 7 and 8 has been merged, and changed a lot.	Det er stadig svært at forstå de 3 illustrative scenarier - Kunne være godt at lave nogle simple flow charts af de tre illustrative scenarier.	Figur tilføjet.
	Table 5: PET og HDPE, Physical-chemical composition: Her er lavet antagelser (udgangspunkt i generic waste plastic bottles), så krydserne bør sættes i parentes eller slettes.	Corrected. Crosses have been deleted from Table 5.	OK	
	Linje 894: Nævn at man for komposit har valgt forbrændingsproces …… for municipal solid waste.	Specified.	OK	
	Linje 936: Uklart hvad sidste sætning betyder.	Corrected.	OK	
	Linje 957: "efficiency" mangler	Corrected.	OK	
	Linje 1012-1013: Betyder denne sætning, at der i scenarierne fjernes 13% af affaldet fra affaldsforbrænding i DK? Det lyder af meget, men sætningen er uklar og betyder måske noget andet?	Corrected and rewritten. The 13% was what was added to the amount treated by Dansk Retursystem. Less than 0.1% will be moved from incineration if everything is moved	OK (moved to another section)	
	Linje 1053: Brown glass mangler. Og et komma.	Corrected.	OK	
	Linje 1129: Der skal stå glas og ikke HDPE.	Corrected.	Der er stadig en HDPE tilbage i teksten.	Fjernet
	Linje 1175-1176: Der skal stå PE i stedet for PP.	Corrected.	OK	

	Linje 1120-1188: Det er forskelligt, om A og/eller B ændres for de forskellige materialer. Dette er forvirrende og det forklares ikke, hvorfor der er forskel. Dette bør forklares bedre, og evt. ensrettes (A/B). Opsummering i tabel ville lette overblikket?	Chapter rewritten. We have explained differences between High and low quality, and why A and B are different for different materials.	OK	
	Linje 1179-1182: Der bør måske tilføjes om kommentar om, at der vil være usikkerhed omkring, hvorvidt man kan udsortere komposit emballager med samme udstyr og samme effektivitet som for de øvrige materialer.	Added. "Juice and milk carton containers are not currently part of the return system, nor are separately collected with paper or cardboard. We assumed the same sorting efficiencies of the other packaging materials, which were 97.7 % to high quality recycling and 2.2 % to normal quality recycling for the return system, and overall 72 % for the separate collection. *However, implementation of such scheme would require verifying that composites can be sampled with the same equipment and the same efficiency as the other materials."*	OK	
	Tabel 7, 8 og 9: Sorting efficiency er baseret på den samlede mængde (100	Yes, the total recovered material is based	OK.	

	%) og ikke de 99,9% rene materialer (tabel 7)? Jf. Eq. 4, linje 747. Eller er der noget, vi har misforstået?	on the overall collected material and was calculated as stated in Eq.4. The tables purity, sorting efficiencies and A and B for completeness. The total recycling efficiency corresponds to A*B, the total recovered material is obtained from: purity*sorting*A*B and the amounts are calculated from the total collected material and not only from the "pure" (wanted recyclables) material.		
	Linje 1232 og 1235: Tilføj enhed (kg/ton material = reference flow)	Added in caption of Tables 10 and 11.	OK	
	Linje 1234: Denne tabel må være for SC scenariet (der står RS)?	Caption corrected.	OK	
	Linje 1245: Hvad betyder sætningen?	Corrected. *"PET, HDPE and composite were the beverage packaging materials types with the lowest recycled material when collected via separate collection."*	OK	
	Figur 2: Uddyb enhed på Y akse: (kg/ton = reference flow) I figur teksten står "low quality", -der bør stå "normal quality". Denne fejl går igen i Executive summary.	Corrected.	OK	

	Linje 1373-1379: Flyttes under figur 7, da det opsummerer hele afsnittet.	Corrected.	OK	
	Figur 8: Måske bør man forklare, hvorfor forbrænding af aluminium giver en besparelse (antager at det skyldes udvinding fra slaggen?).	Added. *"Incineration of aluminium results in overall environmental savings due to recycling of aluminium via the aluminium scrap."*	OK	
	Linje 1457: Ufuldstændig sætning	Corrected.	OK	
	Linje 1469-1473: Uklart om der her omtales følsomhedsanalyser (men disse refereres ikke noget sted)? Ellers er sætningen uklar.	Corrected. The text did not refer to a sensitivity analysis in this case, but to different impact categories. The text has been updated as follows: **"**For the PET beverage packaging material, the return system provided the lowest impacts in 11 out of 14 impact categories, while for glass and aluminium RS provided the lowest impacts for all the impact categories assessed. Incineration provided a better performance for PET for the impact categories where energy recovery was	OK	

		more beneficial (OD, HTNC, TE). However, for PET the incinera-tion results for the TE impact category varied only by 3 % from the return system results." The comment about incineration of alumini-um being the best solution for some im-pact categories was not correct and has been deleted.		
	Table 15: Relevant at nævne, at SC sandsynligvis kommer på 2. pladsen i de fleste af de mørkegrønne felter. RS er en forbedring (men ikke væsentlig ændring) af SC. De to "end of life" muligheder vil derfor have fordele frem for INC i de samme kategorier, men RS altid bedre end SC. Hvis man ikke er indforstået kan det op-fattes som om SC er en rigtig dårlig løs-ning, da den ikke fremkommer af tabel-len. Man kan også lave "2. plads tabel" som i den foregående rapport om shopping bags.	Agree. A clarifying sentence was added to the report. *"Although SC is rarely displayed in the Table, it is relevant to mention that results for the SC end-of-life provided the second best results for most of the dark green fields (which represent RS). RS end-of-life represents an im-proved SC and the end-of-life options therefore are likely to have advantages over INC in the same im-pact categories, but with RS always provid-ing a better perfor-mance than SC. Such*	OK Dette er dog en vigtig pointe og bør fremhæves ved afsnit deling inden kommentaren (linje 1789). Måske bør det også indgå som en del af summary og konklusion? Ellers kunne nogle tolke det som om INC er bedre end SC.	Enig. Tilføjet i Summary og konklusion

		results can be observed from the characterized results scores presented in Tables 12-14."		
	Table 16, 17 og 18: Der er ikke tale om impacts kontra savings, da alt er impacts. Det er en rangording af tallene. Gælder også teksten f.eks. linje 1571-1572. Forslag: Alle omkostninger kunne være forskellige nuancer af rød (tabel 16). Dette gælder også for table 17 og 18 – her er nogle af de negative værdier f.eks. røde.	Table 16 has been corrected with only red colour scale. Table 17 has been corrected, now all red colour scale and net savings are displayed in green. Table 18 has been corrected, now all positive values are displayed in red colour scale, all negative values in green colour scale.	OK. Tidligere table 17 and 18 er slettet.	ok
	Table 18: Uddyb tabeltekst. Hvad betyder f.eks. negative og positive tal? Der er nogle voldsomme tal for HDPE. Er det korrekt og hvad skyldes det? Kan der laves en oversigt over under -100%, mellem -100% og 0% samt over 0% - f.eks. tal mellem -100% og 0% betyder en procentdel besparelse af produktionsomkostningerne.	We have removed this part as it was confusing.	OK. Tidligere table 17 viste dog den vigtige information, at SC for mange materialer og impact kategorier ern r. 2 efter RS.	Enig, men det var også gjort klart at denne tabel var meget forvirrende. Vi har i stedet tilføjet dette i teksten, og nu som også foreslået gjort det mere klart i konklusion og summary.
	1601: Ufuldstændig sætning (because connected?)	Rephrased. "*Impacts related to transport provided a relatively limited contribution to the overall LCA results for all the waste beverage material types assessed.*	OK	

		The relative contribution to the results for transport was higher for beverage packaging materials that obtained lower benefits from recycling .		
	Linje 1613-1615: Ikke forstået	Rephrased.	OK	
	Line 1617-1619: Ikke forstået. Henviser I til tabel 15 eller 18? Vi kan ikke helt genkende det, som I skriver (f.eks. alle kategorier for PET? Skal det være HDPE? Og ikke alle impact kategorier for komposit materiale). Og hvorfor skal man have høj recycling efficiency, når INC giver bedst resultater?	The whole paragraph has been rephrased and a clear reference to the correct Tables has been made.	OK	
	Figur 11, 12 og 13: Enheden på Y aksen kunne angives i tons med 1000 tals separator? Det er meget store tal.	Figures are updated as suggested.	OK	
	Linje 1691: 4,000 tons (separator og s på tons)	Chapter has been updated, as more products were added.	OK	
	Linje 1718-1719: Modsiger dette statement linje 1725-1726 for HDPE? Hvis det er bedre på de fleste parametre at brænde HDPE er det forvirrende, at det også fremhæves som et materiale, hvor det kan betale sig at genanvende. Forklar evt. bedre.	Text and chapter in general has been fully updated.	Konklusionen for PET er forkert. RS er ikke bedst for PET for alle impact kategorier. Der er 3 kategorier, hvor INC er bedre (table 19). Line 2043-45 er meget uklar. Det fremgår ikke af konklusionen at I kun ser på genanvendelige og ikke genpåfyldelige emballager. Det er at foretrække, at man kan læse summary og konklu-	Konklusion gjort klarere, og har nu alle disse pointer med.

			sion separate fra resten af rapporten og stadig få de store linjer med i forhold til formål, metode og resultater.	
	Kender I Forces rapport om pantsystem i Grønland? Jeg manglede den i reference-listen.	Har ikke rapporten. Vi har valgt ikke at have et større literatur stu-die. Så vidt jeg kan se er studiet lavet med GABI og ecoinvent, og ville derfor ikke kunne sammenlignes.	OK	
	Table A1: Glass i stedet for galss	Corrected.	OK	
	Table A2: Er det ikke den samlede mængde impurities, der skulle give 0.1 kg/ton	No, the sum of the impurities is 1 kg. The purity was assumed 99.9%, which means 0.1% impurity, which is 1 kg over 1000 kg of reference flow.	OK	

Tjekliste

Følgende skal være dækket af tredjepartsrapporten

Aspekter fra ISO 14044	Kommentarer fra COWI, første runde Linjenummer refererer til rapport, version marts 2018	Svar på kommen-tarer fra DTU Miljø Linjenummer refererer til rapport, version marts 2018	Kommentarer fra COWI, anden runde Linjenummer refererer til rapport, version maj 2018	Svar på kommentarer fra DTU Miljø Linjenummer refererer til rapport, version maj 2018
1 Generelle aspekter				
1.1 livscyklusvurderingens opdragsgiver, udøveren af livscyklusvurderingen	√			

1.2 rapportens dato	√			
1.3 erklæring om, at vurderingen er udført i overensstemmelse med kravene i ISO 14044	√			
2 Vurderingens formål				
2.1 grundene til at foretage vurderingen	√			
2.2 dens påtænkte anvendelser	√			
2.3 målgrupperne	√			
2.4 erklæring om, hvorvidt vurderingen påtænkes at understøtte sammenlignende påstande, som er beregnet til offentliggørelse	√			
3 Vurderingens afgrænsning				
3.1 funktion, herunder				
a) erklæring om ydeevneegenskaber	√			
b) eventuel udeladelse af yderligere funktioner i sammenligninger	√			
3.2 funktionel enhed, herunder				
a) overensstemmelse med formål og afgrænsning	The temporal scope er angivet til at være 2017 (linje 575), men tilhørende beslutningsperiode er 2020-2030 (linje 617, 984 mm.). Der er også anvendt energidata for denne periode. Måske er temporal scope i virkeligheden 2020-2030 med ud-	The study assesses the life cycle environmental impacts associated with the management options available nowadays (which is the beginning of 2018) for beverage packaging waste. In order to carry out such assessment, we had to base the LCA on the	OK	√

	gangspunkt i mængder mv. fra 2017? Det gælder funktionel unit (linje 551-554) og linje 575. I introduktionen refereres til 2018 (linje 340).	available data on amounts and composition of beverage packaging waste, therefore the functional unit and reference flow state "2017", which is the latest available year for data gathering. Regarding the choice of marginal energy technology, as explained later, since the study is assumed to support decisions that will occur in a 10 year period, using a future marginal energy is assumed to well represent the effects in the future waste management system. Moreover, this LCA study is part of a series of assessments conducted by DTU for the Miljøstyrelsen in the end of 2017 regarding decision support for future waste management options. All the assessments are based on the same marginal energy choices.		
	Det er ikke defineret i den funktionelle enhed at: -Man kun ser på genanvendelige og ikke	Text has been rewritten	OK	√

	genpåfyldelige emballager -Kun der kun inkluderes mælk og juice emballage, som i dag sælges i glas, alu og plast (og ikke andre drikkevarer eller mælk/juice i andre emballager).			
b) definition	Lidt vanskeligt at forstå præcist hvilke drikkevareemballager, der er inkluderet i vurderingen. Bør skrives helt tydeligt, at der er tale om emballager til juice og mælk i emballager af plast, metal, glas og komposit, der i dag ikke er inkluderet i pantsystemet. Især afsnit 2 forvirrer.	Text has been rewritten	OK	√
c) resultat af ydeevnemåling	√			
3.3 systemgrænse, herunder				
a) udeladelser af livscyklusfaser, processer eller databehov	√			
b) kvantificering af energi-og materialeinput og –output	Antagelsen om at kvaliteten af glas genanvendelsen er højere i pantsystemet end ved SC kan ikke retfærdiggøres, da alt glas, der indsamles og genanvendes i DK, er food grade kvalitet. Desuden	Text has been rewritten	OK	√

	behandles glasset på samme anlæg (Reiling).			
	Food grade / non food grade modellering: Modellering af denne forskel i kvalitet er baseret på en øget genanvendelse og afspejler ikke forskel i selve substitutionen (substitution af forskellige typer produkter). Denne usikkerhed håndteres ok.	The food grade substitutes a higher quality PET because data about food-grade PET were available – for the remaining beverage material types higher recycling quality was modelled by increasing the recycling efficiency (both A and B).	OK	√
c) antagelser vedrørende elektricitetsproduktion	I valgt en fremtidig marginal for elektricitet - Er dette korrekt når nu FU siger 2017? Angiver, at beslutningsperioden er 2020-2030.	Please see above under “temporal scope” Since the study is assumed to support decisions that will occur in a 10 year period, using a future marginal energy is assumed to well represent the effects in the future waste management system. Moreover, this LCA study is part of a series of assessments conducted by DTU for the Miljøstyrelsen in the end of 2017 regarding decision support for future waste management options. All the assessments are based on the same marginal energy choices.	OK	√

3.4 afskæringskriterier for den indledende/første medtagelse af input og output, herunder				
a) beskrivelse af afskæringskriterier og antagelser	√			
b) udvælgelsens indvirkning på resultater	√			
c) medtagelse af afskæringskriterier for masse, energi og miljø	√			
4 Livscykluskortlægning				
4.1 dataindsamlingsprocedurer	√			
4.2 kvalitativ og kvantitativ beskrivelse af enhedsprocesser	Der savnes beskrivelse af f.eks. om processerne inkluderer biomassebegrænsning. Relevant for genanvendelse af pap fra komposit emballage. Eks. linje 1532 ff., men også før.	Biomass was not considered a limited resource, and this has been added in the system boundaries description. This would have been only marginally relevant for climate change results for composite material recycling (cardboard), which would have provided slightly lower impacts.	OK	√
4.3 kilder til udgivet litteratur	Hvad er kilden til indsamlingseffektiviteter for SC (linje 765)?	Text has been rewritten and sources added	OK	√
4.4 beregningsprocedurer	√			
4.5 validering af data, herunder				
a) datakvalitetsvurdering	√			
b) behandling af manglende data	√			
4.6 følsomhedsanalyse til raffinering af	Er der foretaget føl-	Text has been rewritten .	Vi mener ikke, at dette	Der er tilføjet yderligere følsom-

systemgrænsen	somhedsanalyser???	The scenarios in 7.3 and 7.4 are the sensitivity scenarios we added. We have not made further scenarios.	kan betegnes som egentlige følsomheds-analyser. Vi forstår følsomhedsanalyser som variationer, hvor enkeltparametre eller input ændres for at analysere effek-ten/vigtigheden af den enkelte parameter. Afsnit 7.3 forklarer hvor-for der er forskel mellem materialerne, men kan ikke betegnes som følsomhedsanalyser. Afsnit 7.4 er kombinati-onsscenarier og ikke følsomhedsanalyser.	hedsanalyser i appendix, og ind-sat reference hertil
			Man kan diskutere, om der burde inklu-des yderligere scena-rier, eller evt. bare oplistning af andre relevante scenarier. F.eks. (1) hvis produ-center, der nu leverer i tetrapak, skifter til glas/plast/metal em-ballager (f.eks. for at være miljøvenlige, -indgå i pantsystemet). Dette ville udvidde mængderne i scena-rierne. (2) Eller kunne man forestille sig at inkludere tetrapak i pant-systemet? Det har I selv åbnet for ved at analysere mil-	Vi har valgt ikke at gøre yderli-gere, og kun diskuteret dette. Resultaterne kan let bruges til at lave flere scenarier, men de vil rent være baseret på anta-gelser som er meget usikre. Vi har relativt god viden om mængder lige nu, og nuvæ-rende håndtering så har valgt at holde fokus på dette. Kom-posit materialer er medtaget da det blev gjort klart fra følge-gruppen dette kunne være en følgeeffekt, så vi har dette med som scenarie, men med klar-hed over at det har store usik-kerheder.

			jøeffekterne ved tetrapak i RS (mono materials).	
4.7 allokeringsprincipper og –procedurer, herunder				
a) dokumentation og begrundelse for allokeringsprocedurer	Jeg kan ikke læse om der er anvendt biomassebegrænsning eller ej. Relevant for genanvendelse af pap fra komposit emballage.	Biomass was not considered a limited resource, and this has been added in the system boundaries description. This would have been only marginally relevant for climate change results for composite material recycling (cardboard), which would have provided slightly lower impacts.	OK	
b) ensartet anvendelse af allokeringsprocedurer	√			
5 Vurdering af miljøpåvirkninger i livscyklus, hvis anvendt			Det bør anføres i teksten, at der anvendes de impact kategorier, som ILCD anbefaler. Lige nu står det kun i tabeltekst til tabel 4.	Omformuleret den første linje til at medtage ILCD "The impact categories for the impact assessment phase were selected on the basis of the ILCD recommended impact factors by the European Commission (2010)."
5.1 LCIA-procedurer, beregninger og resultater af vurderingen	√			
5.2 begrænsninger af LCIA-resultater, som vedrører livscyklusvurderingens formål og afgrænsning	√			
5.3 sammenhængen mellem LCIA-	√			

	resultater og formål og afgrænsning				
5.4	sammenhæng mellem LCIA-resultaterne og LCI-resultaterne	√			
5.5	påvirkningskategorier og kategoriindikatorer under betragtning, herunder den logiske begrundelse for, at de er valgt, herunder antagelser og begrænsninger	√			
5.6	beskrivelse af eller henvisning til alle anvendte karakteriseringsmodeller, karakteriseringsfaktorer og metoder, herunder antagelser og begrænsninger	√			
5.7	beskrivelse af eller henvisning til alle anvendte værdibaserede valg i forhold til påvirkningskategorier, karakteriseringsmodeller, karakteriseringsfaktorer, normalisering, gruppering, vægtning og, andre steder i LCIA-en, en begrundelse af deres anvendelse og påvirkning på resultaterne	Ikke relevant			
5.8	en erklæring om, at LCIA-resultaterne er relative udtryk, som ikke forudsiger påvirkninger på kategori-end-point, eller overskridelser af tærskelværdier, sikkerhedsmarginer eller risikoniveauer og, når medtaget som en del af livscyklusvurderingen (LCA), også	√			
	a) en beskrivelse af og begrundelse for definitionen og beskrivelsen af eventuelle nye påvirkningskategorier, kategoriindikatorer eller karakteriseringsmo-	na			

	deller anvendt til LCIA'en				
b)	en fremstilling af og begrundelse for eventuel gruppering af påvirkningskategorierne	na			
c)	eventuelle yderligere procedurer, som omregner indikatorresultaterne, og en begrundelse for de valgte, referencer, vægtningsfaktorer etc.	Na			
d)	en eventuel analyse af indikatorresultaterne, fx følsomheds- og usikkerhedsanalyse eller anvendelse af miljødata, herunder eventuel betydning for resultaterne	Er der foretaget følsomhedsanalyser?	For the materials assessment uncertainties addressed as discussion of influence of data and assumptions on the results. The high-quiality recycling efficiencies were tested as sensitivity analysis by lowering the assumed values to those of normal quality recycling, and the effects are discussed in 7.4. The assumed values do not influence the overall conclusions.	OK	
e)	data og indikatorresultater fra før en eventuel normalisering, gruppering eller vægtning skal gøres tilgængelige sammen med de normaliserede, grupperede eller vægtede resultater	√			
6	Livscyklusfortolkning				
6.1	resultaterne	√			

6.2 antagelser og begrænsninger, som vedrører fortolkningen af resultater, både metodik- og datarelaterede	√			
6.3 datakvalitetsvurdering				
6.4 fuld gennemskuelighed, hvad angår værdibaserede valg, logiske begrundelser og ekspertvurderinger	√			
7 Kritisk review				
7.1 navn på og tilhørsforhold for de personer, der udfører review	√			
7.2 redegørelse fra kritisk review	√			
7.3 svar på anbefalinger fra det kritisk review	Kommer senere			

18

Life Cycle Assessment of management options for beverage packaging waste

The current return system for beverage packaging waste constitutes an optimized recycling system that provides high collection efficiency and high quality recycling Further room for improvement of the current recycling of beverage products can be found in other products that are not yet covered by the deposit and return system.

The aim of this study is to assess the environmental sustainability of alternatives for the management of beverage packaging waste from the beverage products that are not currently part of the Danish deposit and return system. The project compares compare the environmental performance of return system, separate collection system and incineration for plastic, glass, metal and composite beverage products. The goal of the assessment is to identify the best waste management option for each beverage packaging material type and to develop scenarios on the effects of changes in the current beverage packaging waste management.

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Input til undersøgelse af pant på juice

Dette notat er udarbejdet til DTU af Dansk Retursystem på foranledning af Miljøstyrelsen. Notat skal indgå i Miljøstyrelsens undersøgelse af pant på juiceemballager m.v. Bilaget til notatet indeholder fortrolige data, som kun må anvendes til den specifikke undersøgelse, og som ikke må fremgå i forbindelse med publicering heraf med mindre andet aftales specifikt med Dansk Retursystem. Dansk Retursystem har indgående kendskab til emballager omfattet af pantsystemet samt processer i relation til indsamling, sortering og genanvendelse, og usikkerheden ved de leverede data er derfor lav.

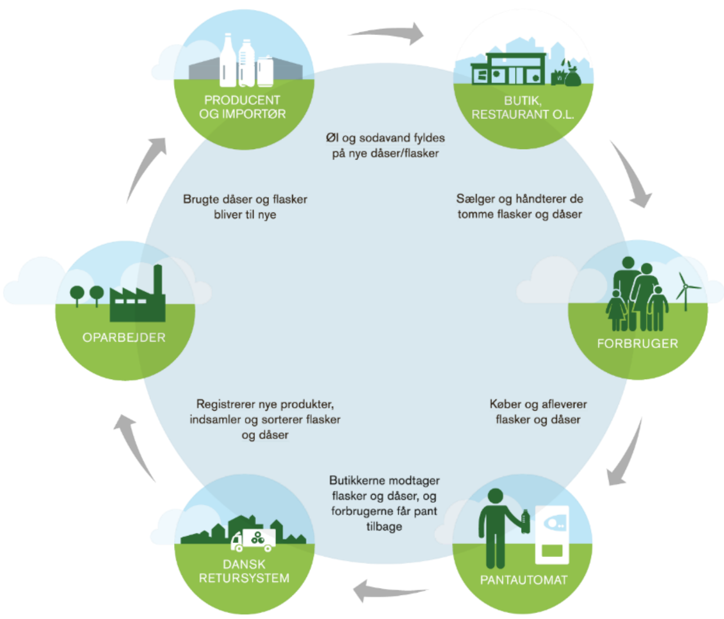
Dansk Retursystem har siden 2000 drevet det danske pant- og retursystem for pantbelagte engangsflasker og dåser i henhold til Pantbekendtgørelsen. Dansk Retursystem repræsenterer et af de mest cirkulære materialekredsløb i Danmark, drives nonprofit, ejes af bryggerierne og ledes af en bestyrelse bestående af repræsentanter for importører, dagligvarehandel og bryggerier med en neutral formand.

Virksomheden indsamler og sikrer årligt højkvalitetsgenanvendelse af over 1,1 mia. emballager af primært plast, glas og metal fra det danske marked. Det skal bemærkes, at der er frit emballagevalg for producenter og importører tilmeldt pantsystemet. 9 ud af 10 solgte emballager med pant afleveres tilbage, og det danske pant- og retursystem har dermed en meget høj og veldokumenteret returprocent for hele Danmark.

Gebyrstrukturen fremmer cirkulære emballager

Indtægter fra salg af genanvendelige materialer udgør sammen med driftsgebyrer og ikke-indløst pant finansiering af systemet. Gebyrer fastsættes årligt på baggrund af omkostningerne ved at håndtere de enkelte emballagetyper med fradrag af indtægten fra salg af det genanvendelige materiale. Det betyder, at gebyrets størrelse er afhængig af både, hvor let emballagen er at håndtere og genanvende samt materialets genanvendelsesværdi. For en emballage fremstillet af sammensatte materialer (komposit), som vanskeliggør genanvendelsen, er gebyret derfor forhøjet. Dansk Retursystems gebyrstruktur, hvor hver emballage betaler for sin egen indsamling m.v. er derfor med til at fremme design af cirkulære emballager, som kan genanvendes igen på samme kvalitetsniveau til nye flasker og dåser til fødevarer.

Pantbekendtgørelsen definerer hvilke drikkevarer, der er omfattet af pantsystemet, og som derfor skal registreres hos Dansk Retursystem forud for markedsføringen på det danske marked. Det er op til producenten eller importøren at vælge enten en engangsemballage, der håndteres af Dansk Retursystem, eller en genpåfyldelig emballage, som skal indsamles af producenten eller importøren selv med henblik på efterfølgende rensning og genpåfyldning. Emballager registreres bl.a. via unikke stregkoder, der gør dem lette at identificere og sortere.



Flest emballager returneres i butikker

Panten udbetales ved køb og tilbagebetales ved returnering. Over 80 procent af alle emballager returneres i dag i butikker med returautomater og er derfor pantafregnet direkte i afleveringssituationen. De resterende 20 procent optælles på Dansk Retursystems to fabrikker.

Indsamling af emballager

92 procent af de butiksoptalte plastflasker og aluminiumsdåser komprimeres p.t. straks efter registrering i returautomaten. På den måde fylder emballagerne mindre til gavn for en miljøøkonomisk indsamling. 58 procent af emballagerne indsamles desuden via specialbyggede biler, der tømmer butikskar med emballager direkte i bilernes kompressionskamre, hvilket er med til at optimere indsamlingen yderligere.

DTU har ønsket indsamlingen opgjort som en vægtmæssig funktionel enhed, men da flasker og dåser overvejende består af lette materialer, er det centralt at være opmærksom på, at der transporteres store volumener, som ikke afspejles i tilsvarende store vægtmæssige enheder. Og selvom Dansk Retursystem vedvarende tilstræber at optimere lasten på biler, er der grænser for, hvor meget emballagerne kan mases sammen, da de også skal kunne adskilles igen i sorteringsprocessen.

Optælling, sortering og klargøring forud for genanvendelse

Emballager fragtes fra markedet til Dansk Retursystems fabrikker, hvor de optælles og/eller sorteres samt klargøres til genanvendelse. Ikke-komprimerede og ikke-optalte emballager optælles ved ankomsten til fabrikkerne, mens komprimerede og optalte emballager transporteres til sorteringsområdet. Plast og aluminium presses hver for sig til industriballer, som stables på trailere til genanvendelse. Glas transporteres til containere, som efterfølgende fragtes som skår til særskilt genanvendelse.

Umiddelbart efter indsamling af emballager fra markedet sorteres og klargøres de på Dansk Retursystems fabrikker for herefter at blive sendt til genanvendelse. Perioden fra returnering af emballager til de er omsat til nye fødevareemballager er dermed meget kort.

I undersøgelsen indgår kWh el til sortering og klargøring af emballager forud for genanvendelsen på eksterne anlæg. Dansk Retursystems el-forbrug på fabrikkerne er dækket af certificeret vindmøllestrøm, idet virksomheden arbejder på at minimere det negative klimaaftryk fra egne aktiviteter[1].

Genanvendelse af emballager

Da engangsemballager fra det danske marked indsamles særskilt, er renheden meget høj. På fabrikkerne sikrer sorteringen blandt andet, at plast og metal adskilles fra hinanden, og grundet den høje renhedsgrad er tab af materialer i sorteringsprocessen minimal. Tabet består af lidt kapsler og labels, der evt. drysser af under sorteringsprocessen, og som virksomheden grundet pladskapacitet ikke p.t. har mulighed for maskinelt at opsamle og forarbejde. I forbindelse med opførelse af en ny fabrik forventes det lille materiale tab af kapsler og labels, at blive reduceret væsentligt.

Plastflasker, aluminiumsdåser og glasflasker udgør mere end 99 procent af de samlede engangsemballager med pant, mens ståldåser og keramikflasker overvejende tegner sig for den resterende andel. Med undtagelse af keramik og stål kan emballagerne blive til nye fødevareemballager og afsættes derfor på kontraktvilkår direkte til anlæg med speciale heri. Anlæggene er placeret i Danmark og den øvrige del af Nord- og Centraleuropa, og samarbejdet indebærer gensidigt, forpligtende krav til den leverede og genanvendte kvalitet. Udover den kvalitetsmæssige performance indgår den transportmæssige afstand også som parameter i udvælgelsen af genanvendelsesanlæg.

[1] Dansk Retursystem har en målsætning om at udlede 33 pct. mindre CO_2 fra egne aktiviteter per indsamlet og sorteret emballage i 2020 sammenlignet med 2014

Mens glas og aluminium stort set kan smeltes direkte om til nye flasker og dåser, bliver plastflaskernes kapsler og labels sorteret fra hos genanvendelsesanlægget. Kapsler og labels bliver genanvendt til andre højkvalitets non-foodprodukter såsom indkøbskurve.